EPRI

Field Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intake Structures

Technical Report

Field Evaluation of Wedgewire Screens for Protecting Early Life Stages of Fish at Cooling Water Intakes

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REPORT SUMMARY

This report presents the results of a field study evaluating the effectiveness of cylindrical wedgewire screens for protecting the early life stages (eggs and larvae) of fish at water intakes. Researchers evaluated a suite of screen design parameters and hydraulic conditions in two different water body types with different representative species. Information in this report increases the performance database for this technology and, as a field evaluation, offers a direct estimate of effectiveness for potential applications at cooling and other water intakes.

Background

Cylindrical wedgewire screens are considered by some to be one of the more promising technologies available for reducing entrainment mortality for early life stages of fish at cooling water intake structures (CWIS). Although laboratory and field studies have evaluated the effectiveness of wedgewire screens in the past, such research effectively ended with the slowdown in new power plant construction during the early 1980s. As a result, the available database on wedgewire screens was insufficient for determining the optimal screen design and operational parameters or estimating the biological effectiveness of this technology. In 2003, EPRI published the results of a laboratory evaluation of wedgewire screens to expand upon the existing database and identify the importance of several design, operational, and biological factors in determining the effectiveness of wedgewire screens (EPRI Report 1005339). The next logical step in developing cylindrical wedgewire screens to the point where they can be considered for general application at CWIS was to evaluate their effectiveness in a field setting. The present field evaluation was sponsored by EPRI, with supporting funds from the U.S. Environmental Protection Agency under the CWA §104(b)(3) Water Quality Cooperative Grants Program (#CP-83080701-0).

Objectives

- To determine the applicability of previous laboratory studies to potential field applications of cylindrical wedgewire screens at existing CWIS sites
- To identify, under field conditions, the relative importance of various screen design parameters and hydraulic conditions in minimizing entrainment of early life stages of representative fish species
- To evaluate the effectiveness of cylindrical wedgewire screens for reducing entrainment of early life stages of fish in estuarine and freshwater water bodies.

Approach

To evaluate the effectiveness of cylindrical wedgewire screens, the project team constructed a specially designed mobile floating test facility. The team simultaneously collected paired

entrainment samples through an open port and a test screen. Comparison of entrainment rates though the two intakes provided an estimate of the ability of the test screen to reduce entrainment. Testing was performed in two different water body types, an estuarine site located in Narragansett Bay, Rhode Island and a freshwater site located in Lake Erie, Ohio at the mouth of the Portage River. The screen design parameters evaluated included slot width (0.5 and 1.0 mm) and through-slot velocity (0.15 and 0.30 m/s). The team evaluated the effect of ambient (or approach flow) velocity on entrainment rates at the estuarine test site and also the effect of biological factors, including species and larvae/egg size.

Results

At the estuarine site, testing with the 0.5 mm screen demonstrated a significant reduction in entrainment of 72 percent or more for all species and sizes of larvae combined. While the greatest reduction was observed for grubby and sand lance larvae (≥80 percent), the entrainment of winter flounder was also significantly reduced (≥44 percent). The 1.0 mm screen provided a significant entrainment reduction for grubby larvae (≥45 percent), but not sand lance or winter flounder. The entrainment of shad spp. larvae, the dominant taxa collected at the freshwater test site, was significantly reduced by 50 percent with the 0.5 mm screen operated at 0.30 m/s but not at 0.15 m/s or with the 1.0 mm screen. Entrainment reduction increased as larval length increased. At both test sites, the entrainment of eggs was significantly reduced by the 0.5 mm screen (≥92 percent), but not the 1.0 mm screen. Further study could expand upon the existing database by testing with other species and in other water body types.

EPRI Perspective

This report provides CWIS and other water intake operators with information on the ability of cylindrical wedgewire screens to minimize entrainment and impingement of early life stages of fish and shellfish. Research results will allow water intake designers to configure these screens for optimal effectiveness in different water body types and will allow resource managers to more accurately predict the potential for biological effectiveness at a given site.

Keywords

Fish Protection
Cooling Water Intakes
Clean Water Act Section 316(b)
Wedgewire Screens

ABSTRACT

Cylindrical wedgewire screens are considered a technology that has potential for effectively reducing the entrainment and impingement of fish eggs and larvae at cooling water intake structures. Following a laboratory study in which optimum design and operational criteria were identified, a field evaluation of cylindrical wedgewire screens was conducted in 2004 to determine their effectiveness in a field setting. A specially designed floating test facility was constructed, and entrainment sampling took place in two water bodies. An estuarine test site was selected in Narragansett Bay, Rhode Island, and a freshwater test site was selected at the mouth of the Portage River, Ohio, into Lake Erie. Paired entrainment samples were simultaneously collected through an open (control) port and a test screen and densities were compared to provide an estimate of the ability of the test screen to reduce entrainment. Sampling was conducted with two different test screens (0.5 and 1.0 mm slot widths) operating at two different intake (or through-slot) velocities (0.15 and 0.30 m/s). Entrained organisms were identified and measured to determine species- and size-specific entrainment rates. Slot velocity did not have a significant effect on entrainment rates. For all larval species and length classes combined, mean entrainment through the 0.5 mm screen was significantly reduced (≥72 percent) compared to the control port for trials conducted at the estuarine site. The greatest reduction was observed for grubby and sand lance larvae (≥80 percent). However, the 0.5 mm screen also significantly reduced mean winter flounder entrainment (≥ 44 percent). The 1.0 mm screen significantly reduced the mean entrainment of grubby larvae (≥45 percent), but not sand lance or winter flounder larvae. For shad larvae collected from the freshwater test site, mean entrainment was significantly reduced (50 percent) with the 0.5 mm screen operated at a 0.30 m/s slot velocity, but not with the 1.0 mm screen. The degree of entrainment reduction typically increased as larval size increased. A significant reduction in mean egg entrainment (≥92 percent) was observed at both sites with the 0.5 mm screen but not the 1.0 mm screen.

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INTRODUCTION

In the Phase II Rule for implementing Section 316(b) of the Clean Water Act, the U.S. Environmental Protection Agency (EPA) established performance standards as a metric for measuring the effectiveness of compliance alternatives. The performance standards established by EPA require a reduction in impingement mortality of 80 to 95 percent at all facilities and, for some facilities, a reduction in entrainment of 60 to 90 percent. Cylindrical wedgewire screens are considered by some to be one of the more promising technologies available for reducing impingement mortality and entrainment (IM&E). EPA used existing effectiveness data for cylindrical wedgewire screens, in part, in its justification of the performance standards for IM&E reduction, and wedgewire screens are the only technology currently pre-approved for reducing IM&E at CWIS in freshwater rivers under the rule.

Cylindrical wedgewire screens have a "V" or wedge-shaped, cross-section wire welded to a framing system that forms a slotted screening element (Figure 1-1). Previous studies have shown that the following conditions are important for preventing or reducing entrainment and impingement associated with wedgewire screens (EPRI 1999): (1) a sufficiently small slot size to physically block passage of the smallest life stages to be protected; (2) low through-slot velocity (i.e., the water velocity between wedgewire slots) to minimize the hydraulic zone of influence in which passive or weak swimming organisms can become entrained; and (3) an adequate ambient velocity (i.e., “sweeping” velocity) passing across a screen to carry organisms and debris along and away from the screen. When all of these factors exist, it is expected that the biological effectiveness of wedgewire screens will be high. However, large reductions in entrainment and impingement may occur when sub-sets of these conditions exist. For example, low through-slot velocities and high approach velocities may reduce entrainment and impingement to acceptable levels, even when aquatic organisms are physically capable of passing through slots.

The available data, however, were not adequate for determining which parameters, or combinations of parameters, may need to be optimized for effective future applications. Consequently, EPRI and EPA funded a laboratory study to determine, under controlled conditions, the influence of important biological and engineering parameters to determine how they contribute to reductions in entrainment and impingement at cylindrical wedgewire screen facilities (EPRI 2003). Because the present study is a continuation of this effort, a more detailed description of the laboratory study follows.

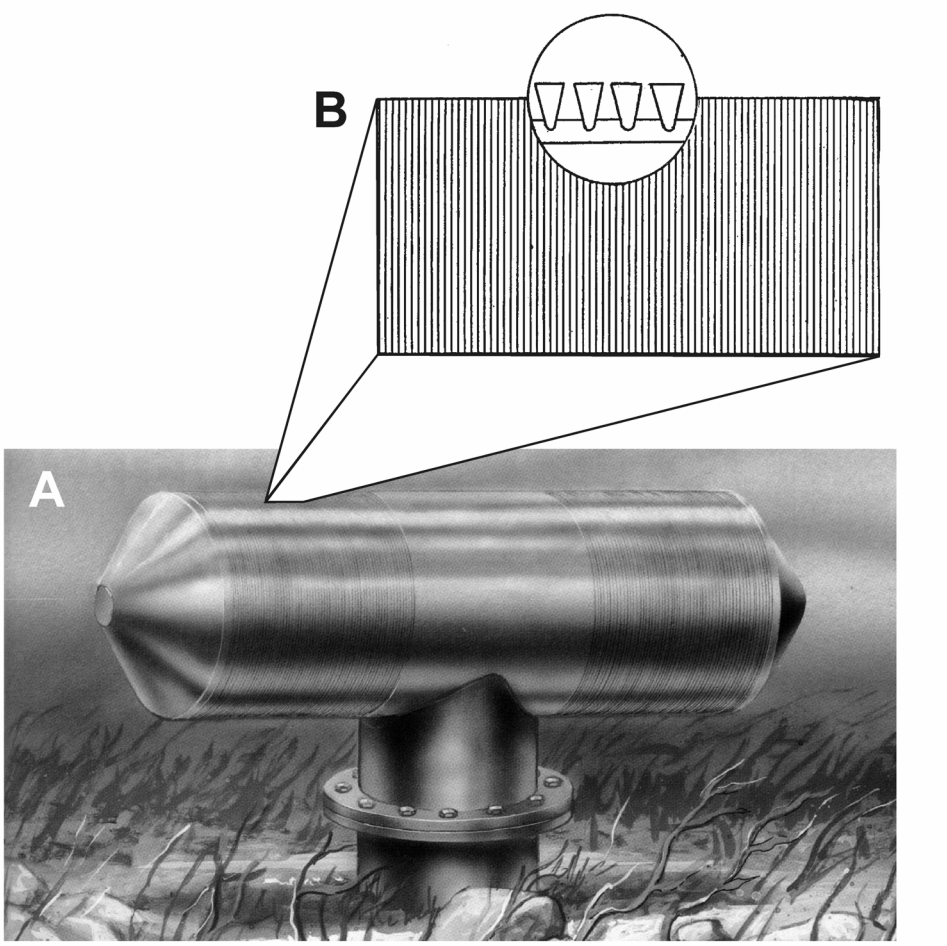

Figure 1-1
Depiction of a Cylindrical Wedgewire Screen Installation (A) and Close-up of Slotted Wedgewire Elements (B) (EPRI 2003, Modified from Hanson 1978 and EPRI 1999).

EPRI Laboratory Evaluation

The purpose of the EPRI laboratory study (EPRI 2003) was to determine, under controlled conditions, the relative importance of various screen design parameters and hydraulic conditions in minimizing entrainment and impingement of selected species and life stages. Entrainment and impingement rates were evaluated for early life stages of eight fish species (striped bass, winter flounder, yellow perch, rainbow smelt, common carp, white sucker, alewife, and bluegill) commonly entrained and/or impinged at CWIS. The following are descriptions of the screen design and hydraulic parameters that were examined in the laboratory flume. Screen orientation is the direction in which the axis of the test screen is oriented (either parallel or perpendicular) relative to the approaching ambient flow. Slot width (or slot size) is the spacing between the wire elements that make up the test screen. Screens with slot widths of 0.5, 1.0, or 2.0 mm were evaluated. Slot velocity (or through-slot velocity) is the velocity of water as it moves through the slots of the screen. Testing was conducted with slot velocities of 0.15 or 0.3 m/s. Ambient velocity (or sweeping velocity) is the velocity of water in the vicinity of test screen. In the case of laboratory testing, ambient velocity was the velocity of water in the flume (or channel

velocity) as it approached the test screen. Tests were conducted at ambient velocities of 0.08, 0.15, or 0.3 m/s.

During testing, known numbers of fish were released upstream of the screens for each set of test conditions evaluated. Impingement was estimated by counting eggs and larvae that were impinged on a screen at the completion of a test and entrainment was estimated by collecting and enumerating organisms that passed through the screens. In general, entrainment increased as slot size and slot velocity increased and decreased as ambient velocity and larval length increased. Impingement also increased with slot and ambient velocity, but decreased with slot size. Interrelationships existed among the various test parameters (e.g., the effects of slot velocity were not uniform for all slot sizes evaluated and response of larvae to varying hydraulic conditions was related to fish size and swimming ability). In addition to these findings, detailed hydraulic flow patterns near wedgewire screens were provided through a comprehensive, three-dimensional Computational Fluid Dynamics (CFD) analysis.

The results of the laboratory study demonstrated that cylindrical wedgewire screens are capable of reducing entrainment and impingement rates to low levels for most species and life stages of fish. In addition, this study identified a narrower range of screen design and hydraulic parameters that optimize effectiveness in a laboratory setting. The next logical step in developing wedgewire screens to the point where they can be considered for general application at CWIS was to perform field evaluations at locations in different water body types with different species, varied flow regimes, and in the presence of suspended debris.

Previous Field Studies

Several wedgewire screen field evaluations have been conducted over the past 25 years. However, the range of fish species and operational and design parameters that have been evaluated remains limited. Taxa for which the most comprehensive data exist include striped bass (EA Science and Technology 1986; Ehrler and Raifsnider 1999), clupeids (Otto et al. 1981; Zeitoun et al. 1981a,b), and bay anchovy (Browne et al. 1981; Weisberg et al. 1987). The majority of field evaluations tested wedgewire screens with slot widths of 1.0 mm or greater. Screen effectiveness was typically estimated by comparing the densities of ichthyoplankton entrained through a test screen to densities entrained through an open port (a control intake without wedgewire screening) and/or collected from the surrounding water body in tow samples of ambient ichthyoplankton (Browne 1979; Browne et al. 1981; Lifton 1979; Otto et al. 1981; Weisburg et al. 1987; Zeitoun et al. 1981a,b).

Browne et al. (1981) performed tests at an estuarine site in southern New Jersey with 1.0 and 2.0 mm screens operating at a slot velocity of 0.15 m/s and found no significant difference between the two slot widths for nearly all taxa. Compared to an open port, densities in 1 mm and 2 mm screen samples were not always significantly lower. However, ambient sample densities were consistently higher than densities in 1 mm and 2 mm samples.

Otto et al. (1981), conducted tests in the Mississippi River, Illinois with 1-mm slot screens operated at a slot velocity of 0.12 m/s and found that, for a given species, entrainment sample densities were less than densities of ambient samples. In addition, it was suggested that larvae longer than 6 to 8 mm had sufficient swimming abilities to avoid being entrained through the 1-

mm slot screen, despite being small enough to fit through the slots. Otto et al. (1981) also found that larvae over 10 mm in length have exclusion efficiencies approaching 100 percent.

In the intake canal of the Chalk Point Steam Electric Station (Patuxent River, Maryland), Weisberg et al. (1987) evaluated the effectiveness of 1-, 2-, and 3-mm screens by comparing entrainment densities to samples from an open port and ambient samples. In addition, larvae were partitioned into length classes for the two dominant species collected, bay anchovy and naked goby. They determined that the exclusion of both species was generally dependent on larval length. Larvae less than 5 mm in length were not effectively excluded by any of the slot widths. In contrast, more than 47 percent of fish between 5-10 mm and more than 90 percent of fish longer than 10 mm were excluded by a 1-mm screen.

Zeitoun et al. (1981) used prototype 2.0-mm and 9.5-mm wedgewire screens near the southeastern shore of Lake Michigan to predict the effectiveness of a proposed intake for Unit No. 3 of the J. H. Campbell Plant. Effectiveness was estimated by comparing densities of ichthyoplankton pumped through both types of screens to densities pumped through an open port, which represented an experimental control. In addition, surrounding ichthyoplankton densities were estimated by collecting towed (ambient) samples. Concurrent sampling was conducted at two sites, an offshore location (1,067 m from shore) and in the intake canal of Units 1 and 2. The dominant species collected were rainbow smelt, alewife, and yellow perch. At the offshore site, entrainment densities collected through the open port and both screen types were not significantly different. However, samples densities collected through both screen types in the intake canal were significantly less than open port samples. In addition, ambient sample densities at both sites were 11 times greater than sample densities collected through the test screens. There were no significant differences between sample densities collected through the two test screens at either site except during August sampling in the intake canal when sample densities through the 9.5-mm screen were higher than through the 2.0-mm screen. Observed differences in entrainment at the two sites were attributable to localized biological characteristics and water currents.

To varying degrees, the above studies examined different biological and engineering aspects of wedgewire screens and their effects on the successful protection of early fish life stages. However, these studies did not examine a full suite of design parameters for all species of interest at cooling water intakes. Unfortunately, this research ended with the slowdown in new power plant construction in the early 1980s. Thus, the available database on wedgewire screens fell short of allowing current scientists and engineers to determine the optimal design and operational parameters and to estimate the potential biological effectiveness of this technology.

Field Evaluation Objectives

The results of the EPRI laboratory study provided information to support the selection of specific design and operational criteria to improve the biological benefits of field applications. However, the laboratory data reflect the performance of the screens in an environment with uniform flow distributions and without debris or biofouling, which are factors that may affect entrainment rates. Therefore, the next logical step in developing wedgewire screens to the point where they can be considered for general application at CWIS was to perform field evaluations at locations in different water body types. To determine if biological screen performance data collected in

the laboratory are applicable to actual intake installations, the present study tested the biological effectiveness of wedgewire screens at two sites that were representative of CWIS located on important water body types with respect to environmental and biological conditions.

Using optimum design and operational conditions identified in the laboratory study, the primary goal of the present field evaluation was to provide detailed information on the relative susceptibility of naturally-occurring fish species and life stages to entrainment when passing in the vicinity of wedgewire screens located at the different field sites. To achieve this goal, the following objectives were set:

1. Estimate entrainment rates for naturally-occurring fish eggs and larvae exposed to 0.5- and 1.0-mm wedgewire screens in a field environment.
2. Conduct testing in two different water body types (estuarine and freshwater) with different species assemblages and environmental conditions.
3. Estimate the exclusion efficiency of cylindrical wedgewire screens for representative species and the different size classes thereof.
4. Determine the relative importance of design and hydraulic parameters by evaluating the effects of different slot widths (0.5 and 1.0 mm), slot velocities (0.5 and 1.0 ft/sec), and ambient velocities.
5. Develop recommendations for optimum design and operational criteria for future wedgewire screen applications and develop expected ranges of entrainment rates for installations in different water body types based on these criteria.

These objectives were addressed by constructing a barge-mounted wedgewire screen test facility from which entrainment sampling was conducted at two field sites. Density-based estimates of entrainment (i.e., number of larvae/eggs per unit flow volume) were calculated for each set of test conditions (slot width/velocity, open pipe). More specific details associated with the design and operation of the test facility are provided in Chapter 2. Details regarding the experimental design, test procedures, and data analysis methods employed to achieve the study goal and objectives are provided in Chapter 3 for the estuarine site and Chapter 4 for the freshwater site. A discussion of the results and how they pertain to future full-scale applications is provided in Chapter 5.

2
TEST FACILITY

General Design

In previous laboratory evaluations of wedgewire screens, a known number of organisms typically were introduced near a test screen and the resulting exclusion efficiency was usually estimated as the mathematical complement of the proportion entrained (EPRI 2003; Hanson et al. 1978; Hanson 1979, 1981; Heuer and Tomljanovich 1978). However, in a field setting the number of organisms exposed to a screen is neither predetermined nor readily quantifiable. Thus, to obtain a measurement of effectiveness in terms of entrainment reduction in the field, a comparison of the number of organisms concurrently entrained through a test screen and an open port was required. To make this approach possible, a test facility was specially constructed to allow for the simultaneous withdrawal of water through a cylindrical wedgewire (test) screen and an open (control) port via two independent pumping systems. This approach is similar to those used by Browne et al. (1981), Lifton (1979), Weisberg et al. (1984, 1987) and Zeitoun et al. (1981a, 1981b).

The floating test facility consisted of two aluminum barges (2.3 x 6.1 m) that could be pinned together to create a 4.6 x 6.1-m test platform (Figure 2-1). This modular design allowed for easier and more cost-effective transportation to and between test sites than would a single, larger barge. Three water intakes were located on the upstream end (bow) of the platform. The port-side (Barge A) intake was capped with a 0.5-mm slot-width cylindrical wedgewire screen and the starboard-side (Barge B) intake was capped with a 1.0-mm slot-width cylindrical wedgewire screen. This permitted the testing of two screen types without repeatedly substituting screens over the course of the study. The center intake consisted of an open pipe that was used for comparison with the wedgewire screen intakes, serving as the study control. A coarse (9.5 mm) mesh screen was installed over the open pipe to prevent the entrainment of large debris. Two fish pumps installed within the hull of Barge A were used to withdraw water through the control intake and whichever wedgewire screen was being tested. The water was then discharged into separate plankton nets at the stern of the barge to collect entrained ichthyoplankton. The samples from each location were analyzed and the observed ichthyoplankton densities were compared for an estimate of the exclusion efficiency of the test screen under various hydraulic and operational conditions.

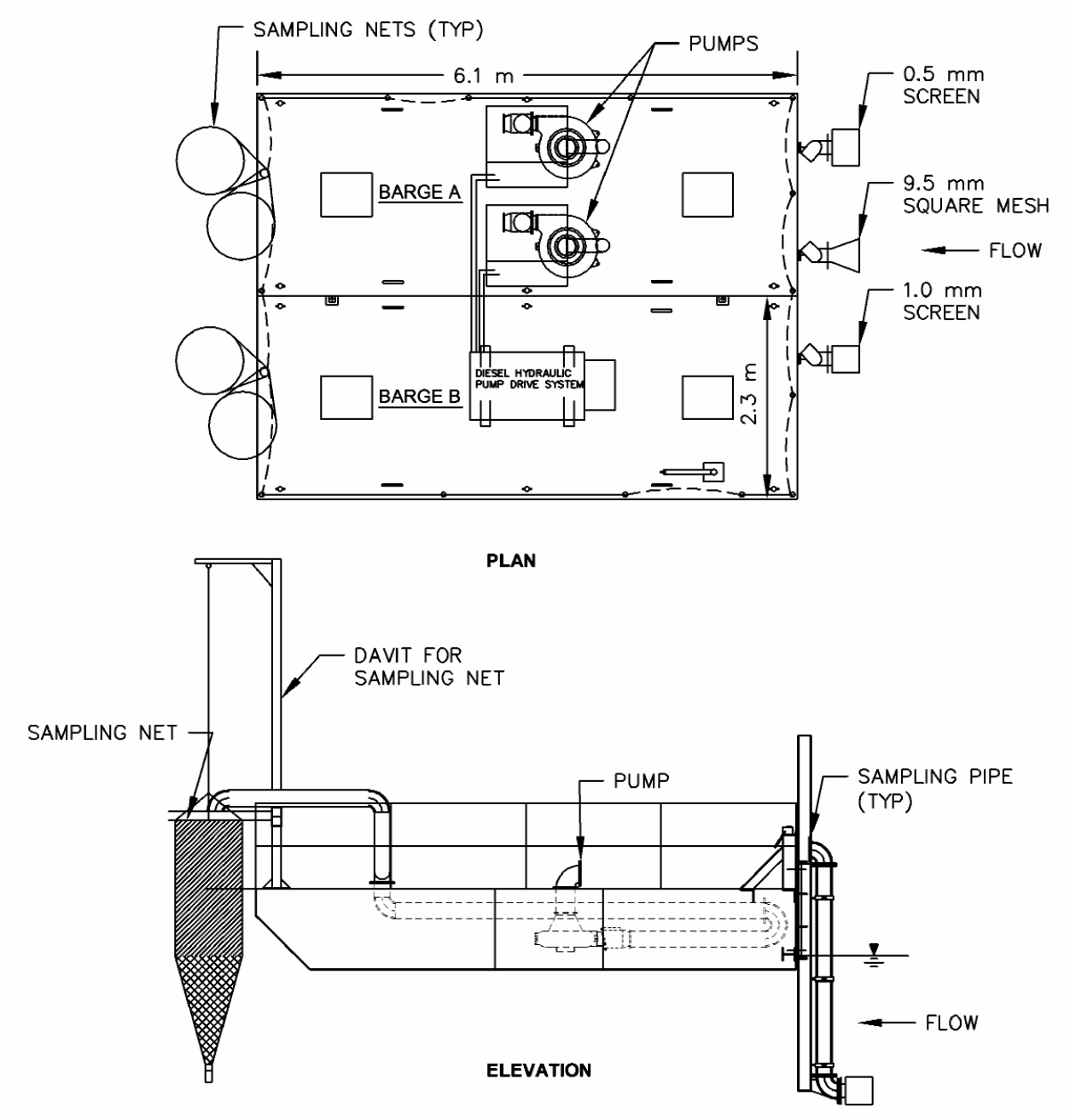

Figure 2-1.
Test Facility in Plan and Elevation View. Note that flexible hoses connecting pumps to sampling pipes have been omitted from both views and the diesel hydraulic pump drive has been omitted from the elevation view.

Test Screens and Control Intake

The two test screens used in this study were single-screen, stainless steel, wedgewire screens purchased from Johnson Screens. The control intake cone was made of aluminum, opened outward, and was capped with a stainless steel mesh screen. A photograph of the actual intakes

is shown on Figure 2-2. To ensure that test conditions were comparable among each intake being tested, the screens and the control intake were sized such that the same intake (or through-slot) velocity could be achieved while sampling at similar flow rates. To this end, the 0.5 mm screen was a standard S-16 screen with a diameter of 41 cm (16 inches), a length of 46 cm, and a discharge diameter of 20 cm. The porosity of the 0.5 mm screen was 23.8 percent. The 1.0 mm screen was a standard S-12 screen, 30 cm (12 inches) in diameter, 36 cm long, and with a discharge diameter of 15 cm. The porosity of the 1.0 mm screen was 38.5 percent. The cone of the control intake was 43 cm long with an opening 38 cm in diameter and a discharge diameter of 15 cm. The open end of the control intake was capped with a 9.5-mm stainless steel mesh that had a porosity of 70.6 percent and was similar that found on most conventional traveling water screens.

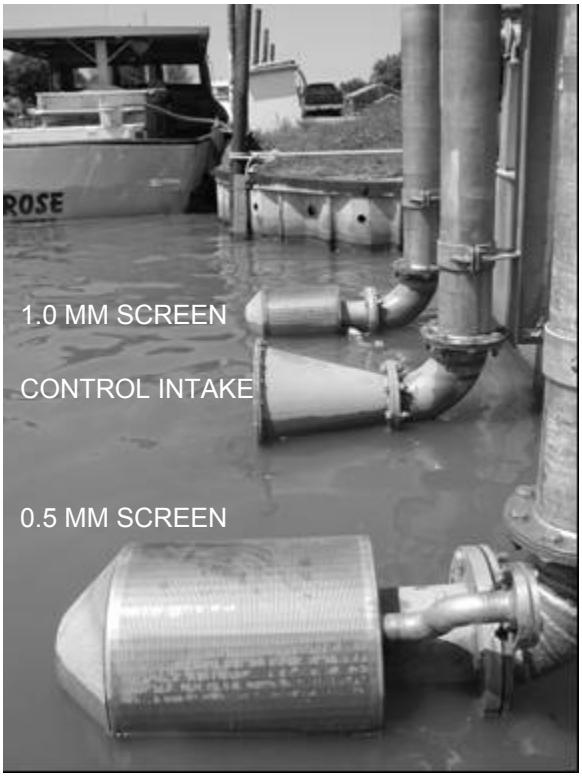

Figure 2-2.
Photograph showing two test screens and control intake at the freshwater test site.

Two different intake velocities were tested during this study, 0.15 m/s and 0.30 m/s. With respect to the two wedgewire screens, intake velocity refers to the velocity of water as it moves orthogonally to the screen's axis through the slots. The control intake was designed (i.e., with a cone shape) and operated such that its intake velocity would approximate the screen intake velocity. Thus, during testing of a given nominal slot velocity at the test intake, the water velocity at the mouth of the control intake would be the same as through the screen slots, albeit unidirectional rather than radial. For the sake of simplicity, intake velocity as it relates to both screen and control intakes will hereafter be referred to as slot velocity.

In designing the test facility, careful consideration was given to determining the appropriate spacing between each intake. Placing the intakes sufficiently close to each other would help to minimize the effects of variations in ambient ichthyoplankton densities and reduce the overall size of the test facility needed. However, assurances had to be made that the hydraulic zone of influence of one intake would not overlap with that of another. Therefore, a computational fluid dynamics (CFD) evaluation was performed to model water velocities and streamlines of each screen at the highest slot velocity (0.30 m/s). The results of the evaluation demonstrated that, under these conditions, neither screen would hydraulically influence or be influenced by the control intake (Figure 2-3). The simulation in Panel A shows the control and 0.5 mm screen operating and Panel B shows the control and 1.0 mm screen operating. The actual on-center spacing of the intakes placed the 1.0-mm screen 1.17 m from the control intake, which was spaced 1.22 m from the 0.5-mm screen. The reason for the difference in spacing was due to the slightly larger zone of influence of the 0.5-mm screen, which had a greater diameter than the 1.0-mm screen.

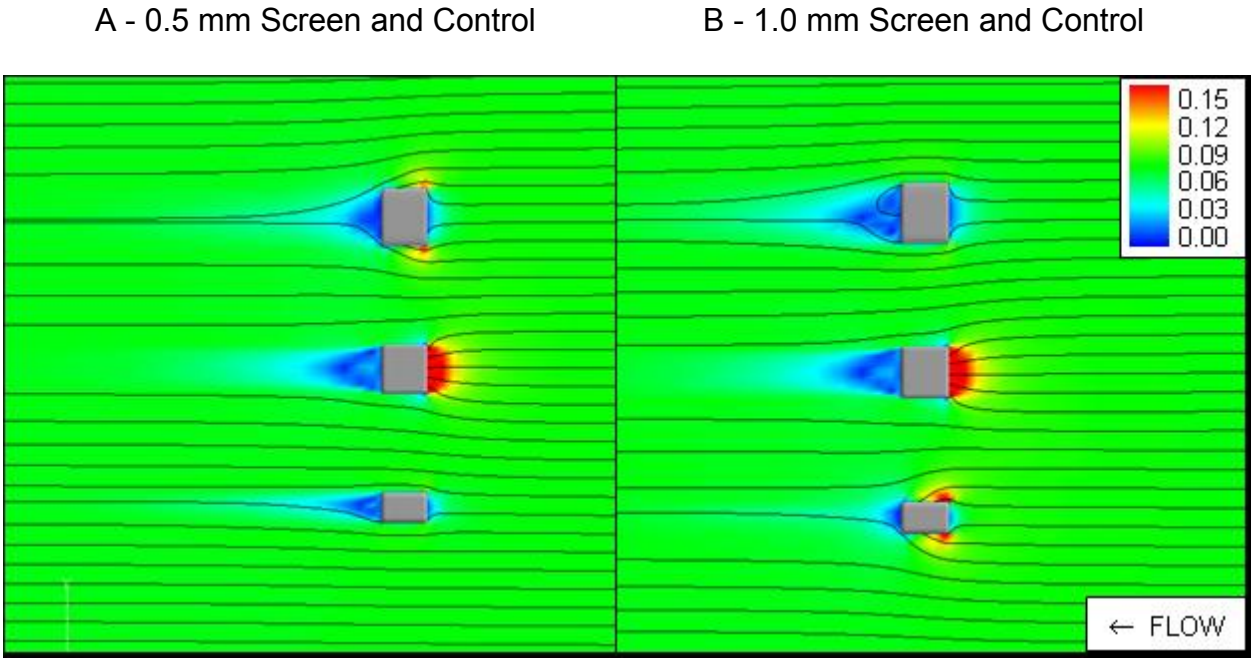

Figure 2-3
Streamline Plots for the 0.5 mm Screen (top), Control (middle), and 1.0 mm Screen (bottom) Withdrawing at a Slot Intake Velocity of 0.30 m/sec in an Ambient Velocity of 0.08 m/s (colored by velocity magnitude in m/s).

Operation

During testing, the control intake and whichever screen was being tested were independently connected to two Aqua-Life fish transfer pumps housed within the hull of Barge A (Figure 2-1). Each pump was rated for 136 to 193 m^3 per hour and was hydraulically driven by a 41 hp John Deere diesel engine coupled to a hydraulic drive pump, both housed on the deck of Barge B. The system allowed for independent variable speed control to fine-tune the pumps to the desired flow rates. To begin operation, the intakes were lowered with a hand winch to the desired

sampling depth and the system was primed using a vacuum primer. The pumps were then activated and set to the appropriate flow rates. Instantaneous flow rates and total volume for each pump were measured with a Signet Model 2517 paddle wheel flow meter wired to a Signet Model 5100 flow monitor. At the initiation of a trial, a technician recorded the starting volume reading for each system while another technician rotated a plankton net into place beneath the corresponding discharge to begin the sample collection. At the end of the trial, the ending volume reading was recorded while each net was removed from the discharge.

Each plankton net consisted of a lower 1.2-m long 335-µ mesh section connected to a 1.5-m long nylon collar. The net opening was 0.75 m in diameter. A platform-mounted davit was used to suspend each sampling net over the stern of the platform such that the mesh portion was submerged in water. In this manner, the physical damage to which any ichthyoplankton in the sampling net were subjected by incoming water was minimized. Upon termination of the trial, a technician washed down the material in each net into a 1-L sample jar affixed to the cod end and preserved it for future analysis. Simultaneously, a second technician shut down the pumps and activated the pressure release valve to purge the water from the system as well as back-flush any debris from the intakes. Although this cleaning method differs from a standard air-burst system typically used at wedgewire screen installations, it was effective at removing material from the surface of the screen. After being purged, the pumps were re-primed and brought back to the appropriate flow rates to prepare for initiation of the next trial. Ambient currents ensured that any material freed during the purge was carried away from the screens prior to activating the pumps. This process (i.e., the time between trials) typically required less than 5 minutes. However, as the time required to wash down the sampling nets was longer, a second pair of plankton nets was used to collect the next set of samples.

In addition to the test and control samples, a third sample was collected to determine the ambient densities of ichthyoplankton in the vicinity of the test facility. A 335-µ plankton net with a 1-m diameter, 3-m length, and 1-m long bridle was used for this purpose. Depending on the amount of ambient current at each site, the net was either deployed off the side of Barge B or towed 20 m behind a motorized johnboat.

Flow Rates and Calibration

Although all three intakes were designed to withdraw a roughly comparable volume of water for a given slot velocity, the actual pump set points were varied slightly by intake type to more closely achieve the desired slot velocity (Table 2-1). Prior to testing, the flow meters were calibrated on site by measuring a range of flows with an orifice plate installed in the intake piping. The differential pressure across the orifice plate, as measured with a differential pressure cell, provided an accurate measurement of the actual flow. Using this information, the flow meters were programmed with a new coefficient. However, because the pumps were operated below their capacity, a further correction was necessary. This was performed using the following equations where x is the actual flow rate in m^3/hour and y is the percent deviation from the actual value of the flow meter readings:

$$\text{Pump 1:} \quad y = -0.0039x + 0.5681$$

$$\text{Pump 2:} \quad y = -0.0039x + 0.6001$$

To ensure that the appropriate slot velocity was achieved, the pump set points were adjusted to reflect this relationship prior to testing and, following testing, the total volume was adjusted accordingly.

Table 2-1
Flow rate set points for each intake and slot velocity.

Slot Velocity (m/s)	Intake	Flow Rate (m^3/hour)
0.15	0.5 mm Screen	67.7
0.15	1.0 mm Screen	61.6
0.15	Control	62.5
0.30	0.5 mm Screen	135.6
0.30	1.0 mm Screen	123.1
0.30	Control	125.1

3
ESTUARINE TESTING

Test Site

Several estuarine sites in the northeastern U.S. were considered for testing. Sites were evaluated based on the abundance and diversity of ichthyoplankton, the timing of ichthyoplankton presence and abundance, physical attributes, and logistical feasibility. After reviewing available ichthyoplankton data and consulting with local researchers, Narragansett Bay, Rhode Island was selected as the estuarine test site. Specifically, the Sakonnet River section of the bay (Figure 3-1) was chosen because it offered higher than average densities of ichthyoplankton, an assemblage of desired species, optimal physical conditions, and, unlike other sections of the bay, there were no dredging operations taking place. The species we expected to collect included sandlance, winter flounder, and fourbeard rockling. Unpublished data (Scherer 2004 and MacPhee 2004) showed that ambient densities of winter flounder larvae, sandlance larvae, and fourbeard rockling eggs at this location during the test period were as high as 150, 100, and 50 per 100 m^3, respectively. Other common species known to exist here were fourbeard rockling and grubby larvae as well as gadid eggs.

The Sakonnet River was also chosen because it offered optimal hydraulic conditions that would facilitate the evaluation of test screens at a range of approach velocities. The test facility was moored at Quality Yacht Services, located in the narrowest section of the Sakonnet River south of the Route 24 bridge near its convergence with Mount Hope Bay (Figure 3-2). The constriction at this location resulted in approach velocities ranging from 0 to 1.1 m/s at the test site. During a typical tidal cycle, there was a one-hour lag between high tide and the time at which the outgoing current commenced. Detailed velocity profiles were collected in front of the test facility to demonstrate flow field uniformity in the vicinity of the intakes (see Chapter 3 Results Section).

The coordinates of the test site were 41° 38’ 10” N, 71° 12’ 46” W, which placed the test facility roughly 100 m from the eastern shore of the Sakonnet River. The water depth at the test site was measured as 15.7 m at mid-tide. The test site was relatively well protected from wind and wave action. Under normal conditions, the test facility was attached to a single mooring ball and the ambient current resulted in its orientation parallel to the ambient current. However, when the wind was sufficiently strong to change the orientation, the stern of the test facility was held in place by attaching it to a second mooring ball downstream.

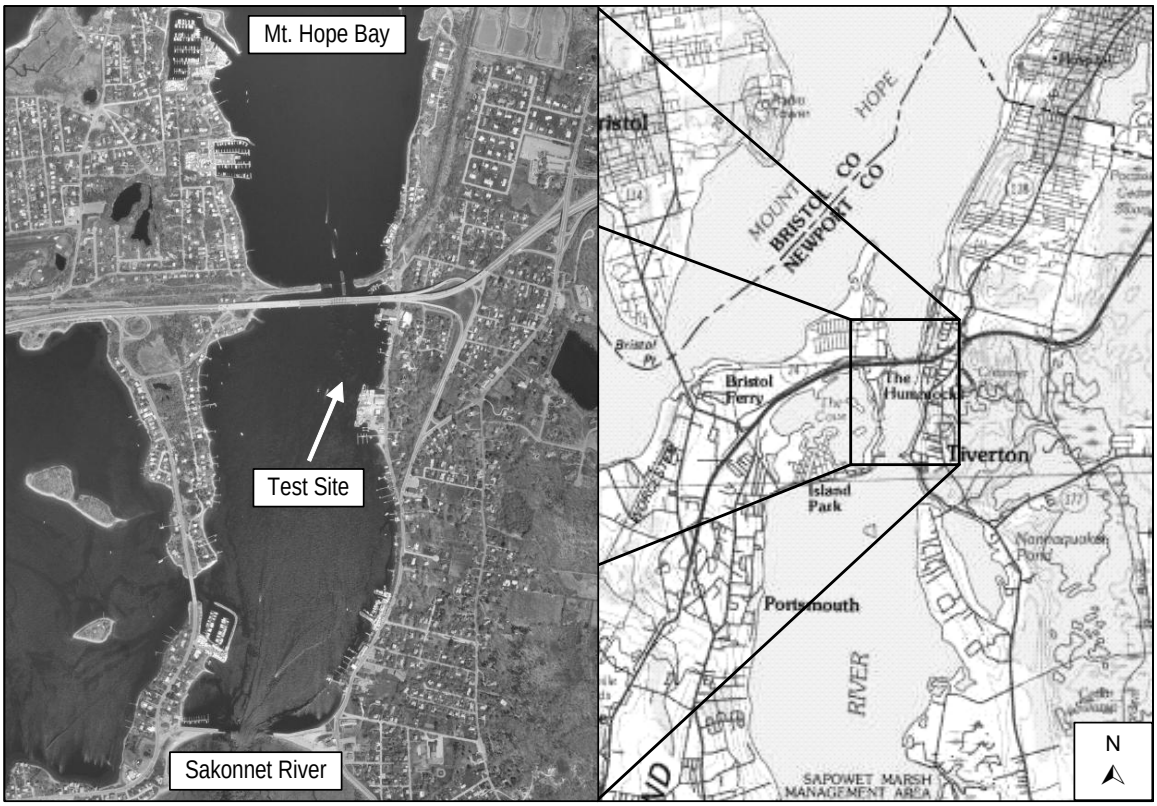

Figure 3-1
Estuarine Test Site in the Sakonnet River

Figure 3-2
Test Facility in Place in the Sakonnet River (facing north)

Methods

Test Procedures

Following preliminary testing to confirm adequate densities of ichthyoplankton and to ensure the proper operation of the test facility, formal testing began on April 7, 2004. Testing was conducted five to seven days per week until all replicates were completed on May 5, 2004. Prior to the first trial of the day, the intakes were lowered to a depth of 1.5 m (on center) below the water surface. Although it was possible to lower the intakes to a depth of 3.0 m, there was concern that the force of the high ambient velocities at the test site (up to 1.2 m/s) would exceed the structural limitations of the test facility. Flexible hoses were then connected from the fish pumps to the control intake and whichever screen was being tested that day, and each system was primed. The pumps were then activated and run for several minutes to allow flow rates to stabilize. As described above, the plankton nets were swung into place beneath each discharge upon initiation of a trial, and volume readings were recorded. Each trial lasted an average of 55 minutes. See Chapter 3 Experimental Design Section for further discussion regarding trial duration.

Because ichthyoplankton abundance is typically greatest in the upper reaches of an estuary, all sampling was conducted during the ebb tide to maximize the number of organisms collected. For safety and logistical reasons, sampling was conducted during the ebb tide with the greatest amount of daylight. However, because of the timing of the tides, sampling was occasionally required under nighttime conditions for up to three hours. Sampling began one hour after high tide and continued until one hour after low tide, based on tide predictions for Anthony Point, which is in the immediate vicinity of the test site.

Every twenty minutes during testing, the ambient water velocity was measured with a Swoffer Model 2100 propeller velocity meter mounted 0.5 m above the control intake. Water quality measurements were taken once during each trial. Turbidity was measured with an Oakton Model T-100 Turbidimeter. Dissolved oxygen, salinity, conductivity, and water temperature were measured using a YSI Model 85 Handheld System. At the end of each trial, a submerged video camera mounted above the test screen was used to record images in an attempt to quantify debris loading and impingement. However, image quality was insufficient to allow these observations.

Six trials were conducted on each day of testing. During the second and fourth trials, representative ambient samples were collected to characterize the densities and species composition of ichthyoplankton from which the control and test samples were collected. More details regarding the sequence of sample collection are described below in the Experimental Design section. Ambient samples were collected by deploying a plankton net 20 m downstream of the test facility off the side of Barge B. A General Oceanics Model 2030R mechanical flow meter was mounted in the mouth of the net to monitor the volume of water sampled. Based on the most recent measurement of ambient velocity, the duration of the ambient ichthyoplankton sample tow was estimated such that the total volume sampled would be approximately 60 m^3. Thus, tows usually lasted from 3 to 5 minutes.

After each sample (test, control, or ambient) was collected, the plankton net was washed down into the 1-L sample jar, making sure that sufficient space remained for preservative to be added.

If the amount of material in the sample was too great to fit in one jar, the sample was split between two jars. Samples were preserved in a buffered, 5 percent formalin solution and dyed with rose-bengal to assist in identification. Sample jars were labeled before being attached to the plankton nets. However, after preservation, an additional label was placed inside the jar for backup identification. Samples were then shipped out in coolers for analysis.

To determine if any organisms were lost during sample preparation, routine quality assurance samples were taken. This consisted of introducing 50 randomly selected larvae into one of the plankton nets. The net was then rinsed down and the larvae were collected according to standard sample preparation procedures. Ichthyoplankton in the resulting sample were then enumerated to determine the percentage of introduced organisms that remained. This was repeated five times over the course of the sampling effort. Collection efficiency ranged from 90 to 100 percent, with an average of 96 percent. Because the collection efficiency was consistently high, and because both the control and test samples were subjected to the same procedures, it was determined that there was not a need to apply a correction factor to density estimates.

In addition to the routine water velocity measurements taken during each trial, detailed mapping of the velocity field in the vicinity of the water intakes was performed on a single day that had an average tidal magnitude. This was done twice during the tidal cycle, at maximum velocity and at average velocity, to determine the uniformity of the flow field as it approached the intakes as well as to confirm that the intakes did not hydraulically influence each other during operation.

Sample Analysis

Samples were processed by Versar, Inc. of Columbia, Maryland which has decades of experience in analyzing ichthyoplankton samples collected from freshwater, estuarine, and marine environments. Upon receipt, samples were processed according to Versar's standard operating procedures, which included detailed quality control procedures. Samples were first washed in a 110-µ sieve to remove the preservative and any fine sediment that may have been collected. They were then sorted to separate ichthyoplankton from other material. During this process, larvae were separated into major taxonomic groups. If ichthyoplankton densities were high, then samples were split. However, a minimum of 100 larvae had to be counted for a sample to be split and this was only done for two samples collected from the Sakonnet River. A minimum of 10 percent of a batch of 10 samples was re-sorted by a different technician for a quality control check of this step. If the resulting estimate of efficiency was less than 90 percent, then the entire batch would be re-sorted.

After sorting, larvae were identified to the lowest possible taxonomic group (typically species) and enumerated. For damaged larvae, only those that had attached heads were counted. If larvae were unidentifiable, they were counted but designated as "unknown". Due to their condition, it was not possible to identify the eggs collected. They were simply counted and classified as eggs. Quality control of the identification step was performed only by a senior taxonomist. This involved the re-identification and counting of approximately 10 percent of each 10-sample batch. If the error rate was greater than 10 percent, then the entire batch of 10 samples was re-identified and counted.

During the identification and enumeration step, the standard lengths of larvae of each species and from each sample were measured in 1-mm increments. For samples in which less than 30 larvae of a given species were present, all intact larvae were measured. In samples where there were 30 or more intact larvae for each species, no less than 30 larvae were measured. In addition, the maximum head width and standard length of a subsample of larvae were measured in increments of 0.17 mm or less using an ocular micrometer. With this information, regression equations of the relationship between maximum head width and standard length for each of the dominant species were calculated. To avoid any bias in this relationship caused by intake selectivity, subsamples were selected from ambient samples only.

A potentially confounding factor in calculating the lengths of larvae collected in this study is the change in specimen size after being held in formalin. Several studies have documented a reduction in larval size following preservation. However, the degree of shrinkage varied by species. Cunningham et al. (2000) found that the length of inland silverside *(Menidia beryllina)* larvae that were preserved for 21 days in 5 percent formalin decreased by an average of 2.2 percent. Sagnes (1997) reported average decreases in the standard length of grayling *(Thymallus thymallus)* larvae ranging from 3.0 to 5.6 percent. In a study of yellow perch *(Perca flavescens)* larvae, Fisher et al. (1998) reported total length reductions of up to 2.5 percent. In contrast Billy (1982) found that tilapia *(Sarotherodon mossambicus)* larvae slightly increased in length following preservation in formalin. Given the lack of information specific to morphometric changes of the species collected in this study, it was not possible to correct for this effect in our length estimates. Nonetheless, this phenomenon should be considered as a potential, albeit relatively minimal, source of error in interpreting the size-specific results described in the following sections.

Because there was little variation in egg diameter at the 1-mm scale at which all larvae were measured, eggs were not measured in every sample. Instead, subsamples of eggs were measured using an ocular micrometer in increments of 0.04 mm. These subsamples were selected from ambient samples to identify the general size distribution, as well as from samples from the 0.5 and 1.0 mm screens to identify any size-based exclusion. Only test samples collected under a 0.30 m/s slot velocity were selected for egg subsampling because it was assumed that the higher slot velocity would represent a "worst-case scenario" in terms of egg exclusion. For each test sample selected for subsampling, the corresponding ambient sample collected at the same time was selected. Up to 30 randomly selected eggs were measured from each sample. It should be noted that, as with larvae, the egg size may change following preservation. In addition, eggs collected shortly after being spawned may not have had a chance to harden, increasing their potential for extrusion through a screen slot even though it may be narrower than the egg diameter.

Experimental Design

The primary independent variables evaluated in this study were screen slot-width (0.5 and 1.0 mm), slot velocity (0.15 and 0.30 m/s), and ambient velocity (range 0 to 1.1 m/s). To evaluate the effect of ambient velocity, each ebb tide was divided into six periods of equal duration, with one trial conducted for each period. Over the course of the ebb tide, water velocity varied from 0 to 1.1 m/s, peaking halfway through the tide. The first and sixth periods were designated as "slow" velocity, the second and fifth periods as "moderate" velocity, and the third and fourth

periods as "fast" velocity. However, ambient velocity varied based on tidal magnitude and was therefore considered a continuous variable. The average velocity over the course of a trial was used for statistical analyses. To evaluate the effect of slot velocity, the pump rates were varied to achieve velocities of 0.15 or 0.30 m/s. The 0.5 mm slot-width screen was used on Day 1, and the intakes were operated at 0.15 m/s during periods one through three. The slot velocity was then increased to 0.30 m/s during periods four through six. This process was repeated with the 1.0 mm screen on Day 2 to complete the first replicate. Because ichthyoplankton densities presumably vary during the course of the ebb tide, we alternated the order in which the different slot velocities were tested. For example, during odd numbered replicates, 0.15 m/s was tested first (i.e., periods one through three) followed by 0.30 m/s (periods four through six). During even numbered replicates, 0.30 m/s slot velocity was tested first. To minimize potential bias from temporal variation in ichthyoplankton composition or abundance, the screen used for testing was alternated daily.

A total of 10 replicates were conducted for each combination of test conditions. For example, 10 trials were conducted with a slot width of 0.5 mm, a slot velocity of 0.15 m/s, and "slow" ambient velocity. Each replicate required two days to complete, for a total of 20 sampling days. Because the duration of the ebb tide varied over the course of the study from five to seven hours, the sample duration typically varied from 45 to 70 minutes. The total volume of water sampled ranged between 33 and 161 m^3 and varied according to the sample duration and test conditions.

Comparing the numbers of eggs and larvae entrained through the test screen to the number entrained through the control intake provided a relative measure of the effectiveness of each screen for reducing entrainment. In addition, to determine the baseline densities of ichthyoplankton from which the test and control samples were collected, ambient samples were also collected. This was done by deploying a plankton net from the downstream end of the barge at roughly the same depth as the test intakes. Ambient samples were collected once for each three-period interval (i.e., during periods two and five) to provide a representative sample for each set of experimental conditions. Although ambient ichthyoplankton samples were not collected at each ambient water velocity, sampling during periods two and five allowed us to account for possible differences in ichthyoplankton densities during each half of the ebb tide.

Data Analysis

The primary means of determining the level of entrainment reduction offered by wedgewire screens was to compare the densities (number per 100 m^3) of ichthyoplankton in the paired test and control samples. Where possible, species, larval size, slot width, slot velocity, and ambient velocity were considered in terms of how they affect this relationship. By collecting paired samples, the variance in sample densities resulting from the inherent patchiness of ichthyoplankton distributions could be accounted for in subsequent analyses.

The statistical approach was based on a "repeated measures" (or "within subjects") design where the "subject" was the ambient population of ichthyoplankton from which the samples were collected and the "repeated measures" were the samples collected from the test and control intakes (Quinn and Keough 2002). The response variable was sample density. Conceptually, this design is analogous to a randomized block design where each trial would be the blocking factor, but allowed for more flexibility in incorporating additional variables and offered a more

intuitive means of identifying the effect of different variables on the difference between test and control densities. Adding slot width and slot velocity as variables yields a between- within-subjects design where intake type (test versus control) was the "within subjects" factor. Slot width and slot velocity were "between subjects" factors because only one slot width and one slot velocity were tested for a given trial. Additional covariates introduced to the model were ambient ichthyoplankton density and ambient velocity. Thus, the resulting model was a repeated measures three factor analysis of covariance (ANCOVA) with two covariates, implemented using the general linear model (GLM; α=0.05). This approach was used independently for each of the primary species collected, as well as for eggs and all species combined. When appropriate, post-hoc comparisons were made using the least significant difference (Fisher LSD) test for pairwise comparisons of cell means (α=0.05).

Because the variance in ichthyoplankton density was high, the densities of all samples (test, control, and ambient) were adjusted using a $\log_e(x+1)$ transformation to meet the assumptions of the model (Sabin and Stafford 1990). Normality was examined using categorized histograms and normal probability plots of the residuals. Levene's test was used for testing the assumption of homogeneity of variance. In instances where these assumptions were not met, nonparametric techniques (described below) were used instead to make direct comparisons. However, violations could typically be attributed to a large number of zeros, particularly in samples collected with the 0.5 mm screen where exclusion was more common.

The effect of larval length was evaluated by grouping larvae into four different length classes. Length classes were approximately centered around the median length for each species so that two length classes fell below the median and two were greater than the median. When possible, the same length classes were used for multiple species to facilitate interspecific comparisons. For grubby and winter flounder, the length classes used were ≤3, 4-6, 7-9, and ≥10 mm. Because sand lance were larger, the length classes used were ≤5, 6-10, 11-15, and ≥16 mm. Separating larval densities into length classes reduced the number of larvae present in each experimental group, which resulted in gross violations of the ANCOVA assumptions. Therefore, a nonparametric approach was used to perform pairwise comparisons between test and control densities independently for each length class and each set of test conditions. While the nonparametric test prevented direct comparisons of different slot widths and slot velocities, it offered a powerful and robust method for identifying significant reductions in entrainment observed under each test condition. This was performed using the Wilcoxon Matched Pairs test (α=0.5), in which test and control samples were paired by trial number (Sokal and Rohlf 1995).

In an effort to minimize the effect of zero-values on normality and homogeneity of variance, trials in which no larvae of a given species were present in either the control or test sample were excluded from the GLM analyses. These values were retained when calculating the mean densities for each set of test conditions and performing the Wilcoxon Matched Pairs test. However, paired zero values have no effect on the statistical parameters of this test.

Because some larvae were damaged and because high larval densities often prohibited the measurement of every larva, the length frequency distribution of the larvae that were measured was applied to the total number of larvae counted. In this manner, the number of larvae in each size class and each species was predicted for each sample even though all larvae were not necessarily measured. In some cases, only a small number of larvae were measurable, despite a

relatively large number of larvae present. Therefore, for the purpose of making comparisons within size classes, trials were excluded from analyses if fewer than 10 larvae were measured. Samples with less than a total of 10 larvae were excluded if fewer than half were measured. In a small number of samples (5 percent), more than 10 percent of the larvae were taxonomically unidentifiable. These samples were also excluded from within-species analyses, but were included in analyses performed on all species combined.

In addition to examining entrainment rates for each length class, the effect of larval length was evaluated by comparing the lengths of larvae in each sample type. For samples collected during trials at a 0.15 m/s slot velocity, the lengths of larvae found in ambient, control, 1.0 mm screen, and 0.5 mm screen samples were compared using the Kruskal-Wallis test (α=0.05; Sokal and Rohlf 1995). Trials at a 0.3 m/s slot velocity were analyzed in the same way. This nonparametric technique was used to minimize the effect of outliers (i.e., large larvae) collected in test and control samples. To minimize the probability of incorrectly rejecting the null hypothesis (the type I error rate) for multiple comparisons, a Bonferroni adjustment was used such that a p-value of 0.0083 (α=0.5 divided by 6 comparisons) indicated a significant difference in length between two sample types. In contrast to larval lengths, the distributions of egg diameters were not as vulnerable to the effect of outliers because extreme values were constrained by the limits of the lifestage. Therefore, where possible, egg diameters in ambient and test samples were compared using a one-tailed t-test to test the null hypothesis that eggs in test samples were not significantly smaller than those collected in ambient samples.

The product-moment correlation (Sokal and Rohlf 1995) was used to evaluate the relationship between larval length and maximum head width. The coefficient of determination (r^2) was calculated to reflect the strength of the relationship, and significance was determined for α=0.5.

Results

During testing, the mean water temperature was 9.0 °C (range 5.1 to 12.2 °C) and the mean dissolved oxygen was 10.0 mg/L. Salinity ranged between 22 and 28 ppt, and typically decreased over the course of the outgoing tide. Turbidity was consistently low, ranging between 0.9 and 2.6 NTU (mean 1.6 NTU). Complete water quality records from the Sakonnet River are provided in Appendix D. The velocity profiles measured in front of the intakes at moderate and high ambient velocities demonstrated a relatively uniform flow field and showed no indication of the intakes hydraulically affecting each other (Figure 3-3).

A total of 11 different species of larval fish were collected in samples from the Sakonnet River. Grubby, sand lance, and winter flounder comprised the vast majority (98 percent) and were the only species for which sufficient data were collected to offer meaningful species specific comparisons. The results comparing entrainment rates through the control intake and test screens under the different test conditions are provided below in separate sections for each species, in alphabetical order. These are followed by the results for all species combined and for eggs. To describe the relationship between the early life stages of each species and fish length, estimated length ranges for yolk-sac larvae, post yolk-sac larvae, and juveniles are provided in Appendix A, as derived from the literature. Raw entrainment data from the Sakonnet River is provided in Appendix B by trial and species.

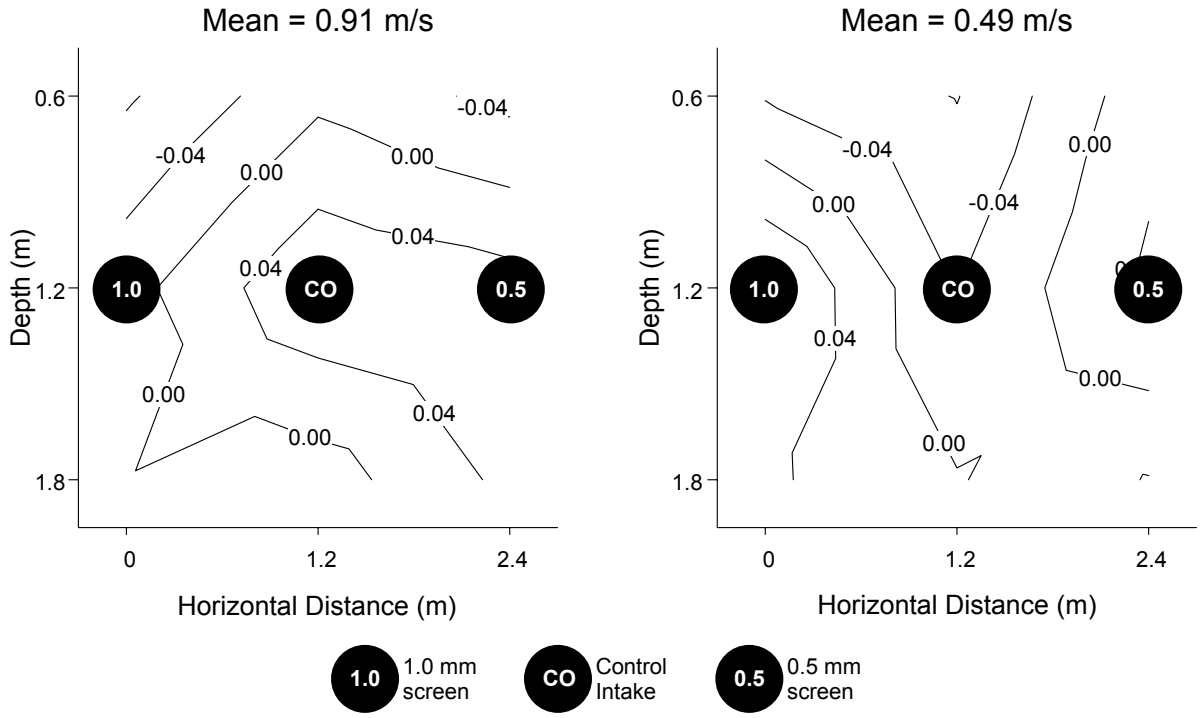

Figure 3-3
Normalized ambient velocity profile in front of intakes at Sakonnet River test site (contour values reflect deviation from the mean approach velocity in m/s)

Grubby

Grubby *(Myoxocephalus aenaeus)* were the third-most abundant larvae collected in the Sakonnet River, representing 13 percent of all larvae collected. Despite their comparatively low densities, they were found in most samples and sufficient data were collected to use the GLM. Intake type (test vs. control) had a significant effect on grubby density. However the intake type/slot width interaction was significant ($p<0.05$), suggesting that the difference between test and control samples was dependent on slot width. The effect of slot velocity was not significant. Post-hoc comparisons revealed that entrainment densities in samples from both 0.5 and 1.0 mm screens were significantly less than in control samples ($p<0.05$). However, entrainment density in 0.5 mm screen samples was also significantly less than in 1.0 mm screen samples. The differences between test and control entrainment densities are shown for each slot width and slot velocity on Figure 3-4 (to graphically illustrate the results of the model, the $\log_e(x+1)$ transformed densities, in numbers per 100 m^3, are plotted).

The ambient ichthyoplankton density covariate was found to be a significant predictor of sample density ($p<0.05$). The ambient velocity covariate was also found to be significant ($p<0.05$), indicating that ambient velocity had an effect on sample density. In addition, the intake type/ambient velocity interaction was significant ($p<0.05$), suggesting that ambient velocity also affected the difference between test and control densities. Figure 3-5 provides plots of test and control densities for each set of test conditions in relationship to ambient velocity. A positive

relationship between ambient velocity and sample density (for both control and test samples) is shown in both panels representing trials with the 1.0 mm screen. In contrast, the panels representing trials with the 0.5 mm screen show only control densities increasing with ambient velocity. Although the significance of the intake type/ambient velocity interaction implies that entrainment reduction was greater at higher ambient velocity, this significance is probably driven more by the consistent exclusion of grubby larvae by the 0.5 mm screen across ambient velocities, and an increase in control densities as ambient velocity increased.

The mean densities of grubby collected in ambient, control, and test samples are shown by test condition in Table 3-1 for each length class. The differences between control and test sample densities are also shown and are indicated where significant. For all length classes greater than 3 mm, test densities were significantly lower than control densities in trials with the 0.5 mm screen ($p<0.05$), with differences greater than 90 percent. This was true for trials with both slot velocities. For trials with the 1.0 mm screen, the difference was significant only for larvae in the 7-9 mm length class, which showed at least an 83.9 percent difference between test and control densities. Although no larvae ≥10 mm were entrained through the 1.0 mm screen, insufficient numbers of larvae of this length class were collected in control samples to demonstrate statistical significance. For all length classes combined, each set of test conditions showed significantly lower densities in test samples when compared to control samples. In general, there was not a noticeable difference in entrainment rates based on slot velocity. For most test conditions, ambient densities were higher than both control and test densities. This trend was observed for most other species as well. Possible explanations for this observation are described in the Conclusions and Discussion section below.

To describe the length distribution of grubby larvae, and to further evaluate the effect of length on entrainment rates, box plots of lengths from each sample type are provided on Figure 3-6 (note that median values may be obscured by boxes when equal to the 25-75th percentiles). At both slot velocities, larvae in the 1.0 mm screen samples were significantly smaller than both control and ambient samples ($p<0.008$). There were no significant differences between any other sample types. However, the lack of significance between 0.5 mm screen samples and other sample types is likely attributable to the small sample size for grubby entrained through the 0.5 mm screen. While length appears to have a significant effect on entrainment rates through the test screen, this effect may be influenced by larval head width. Head width was highly correlated with body length ($r^2=0.90$; $p<0.05$; Figure 3-7). The magnitude of the coefficient of determination (r^2) reflects the degree to which the variation in one variable is explained by the other. Thus, an r^2 value of 0.90 indicates that 90 percent of the variation observed in head width can be explained by length. The relationship also shows that the slope of the regression line was relatively high (0.31), indicating that head width increases fairly rapidly as length increases. This may explain, at least in terms of physical exclusion, the greater differences seen between test and control densities for larger length classes. The length-width relationship also describes the morphology of this species, which can be characterized as more stout-bodied than other species. Based on this relationship, for a length of 5 mm (the median length observed in control samples), the expected head width would be 0.98 mm, which is greater than the width corresponding to the median length of all other species described below.

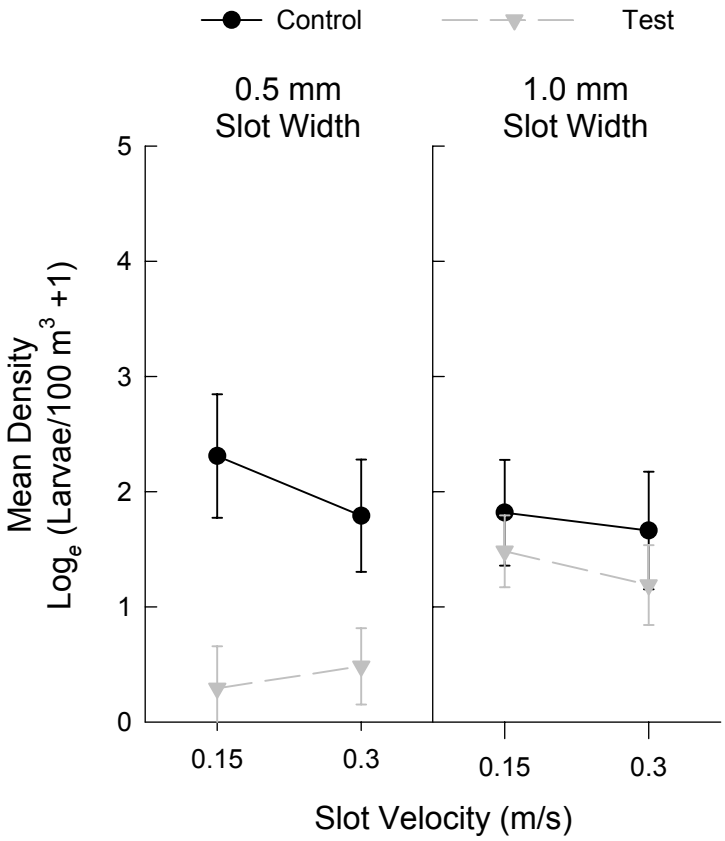

Figure 3-4
Mean Density (log transformed) of Grubby Larvae Collected in Control and Test Samples with 95 Percent Confidence Intervals

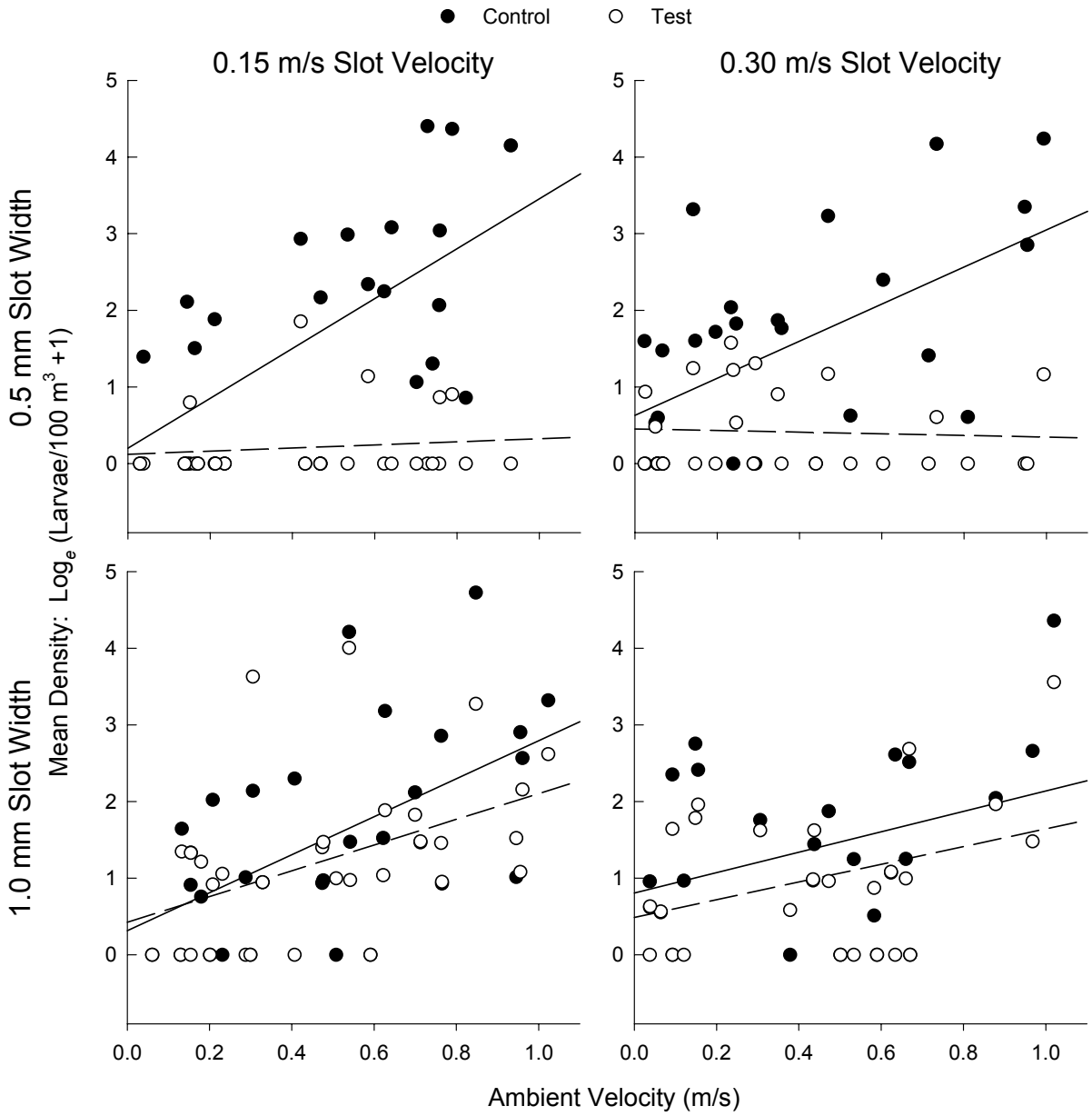

Figure 3-5
Density of Grubby Larvae Collected in Control and Test Samples Plotted Against Mean Ambient Velocity with Regression Lines (Solid = Control; Dashed = Test)

Table 3-1
Mean density and standard deviation (SD) of grubby larvae collected in ambient, control, and test samples during trials with 0.5 and 1.0 mm screens at slot velocities of 0.15 and 0.30 m/s. C-T is the percent difference between test and control densities.[a] Asterisks indicate a statistically significant difference between test and control densities (p<0.05).

Slot Width (mm)	Slot Velocity (m/s)	Larval Length (mm)	Mean Number Entrained per 100 m^3 (SD)			C-T Percent Difference (Valid Trials)
			Ambient	Control	Test	
0.5	0.15	≤3	0.7 (2.4)	0.9 (2.4)	0.1 (0.4)	92.5 (7)
		4-6	12.2 (15.5)	8.9 (14.0)	0.4 (0.9)	95.8 (19)*
		7-9	5.9 (7.9)	3.2 (7.2)	0.0 (0.0)	100.0 (10)*
		≥10	0.8 (1.3)	0.7 (1.7)	0.0 (0.0)	100.0 (5)*
		All	19.5 (23.2)	13.7 (23.2)	0.4 (1.2)	96.7 (19)*
	0.30	≤3	0.0 (0.0)	0.1 (0.5)	0.0 (0.2)	77.8 (4)
		4-6	8.9 (9.2)	7.6 (13.8)	0.7 (1.1)	90.2 (23)*
		7-9	1.6 (3.3)	2.3 (4.9)	0.0 (0.0)	100.0 (12)*
		≥10	0.5 (0.7)	0.4 (0.8)	0.0 (0.0)	100.0 (7)*
		All	12.5 (11.4)	10.4 (18.0)	0.8 (1.1)	92.5 (23)*
1.0	0.15	≤3	0.6 (2.0)	1.5 (3.9)	0.8 (2.5)	44.6 (13)
		4-6	6.5 (5.8)	7.3 (16.6)	4.8 (9.3)	33.7 (26)
		7-9	1.8 (4.8)	1.8 (4.4)	0.3 (1.6)	83.8 (9)*
		≥10	0.8 (2.1)	0.2 (0.9)	0.0 (0.0)	N/A[b]
		All	9.9 (10.3)	10.8 (22.8)	6.0 (11.8)	44.5 (26)*
	0.30	≤3	0.3 (0.9)	0.5 (0.9)	0.2 (0.4)	63.2 (7)
		4-6	3.7 (6.4)	5.2 (12.0)	3.3 (6.2)	35.9 (18)
		7-9	2.6 (5.6)	1.7 (3.5)	0.2 (0.9)	89.1 (10)*
		≥10	2.0 (4.9)	0.0 (0.2)	0.0 (0.0)	N/A[b]
		All	8.6 (16.5)	7.3 (15.3)	3.7 (7.0)	50.1 (21)*

[a] "C-T Percent Difference" is calculated as [(control density minus test density) divided by control density]. Thus, positive values indicate lower densities in test samples.
[b] Insufficient data for meaningful comparison

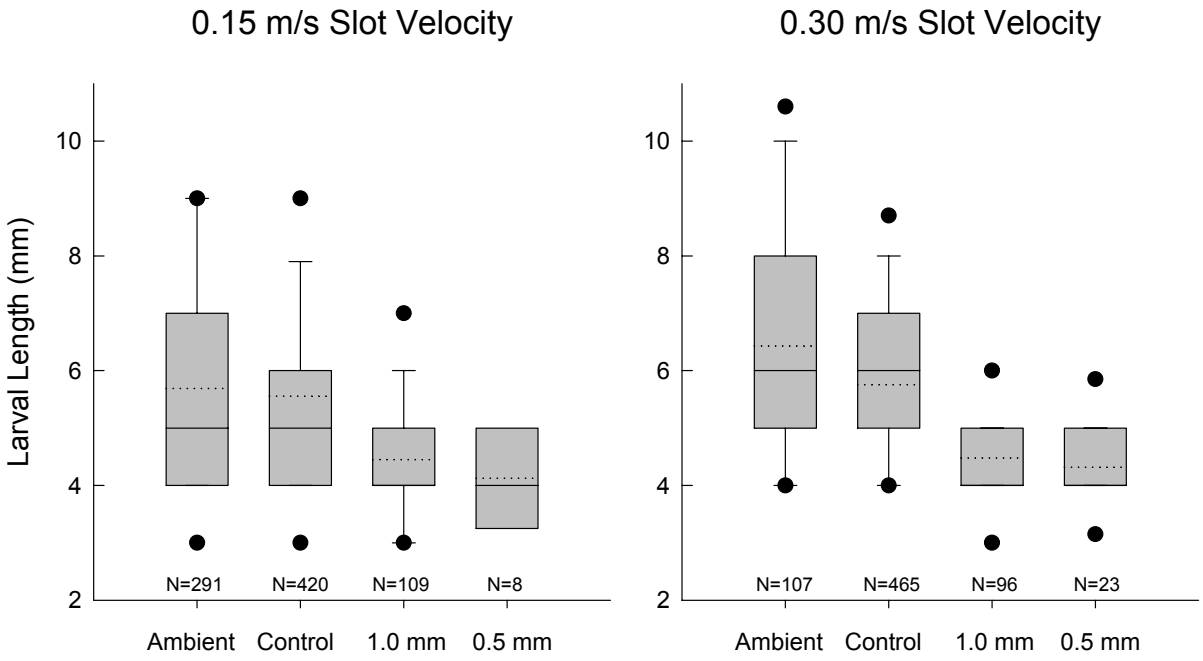

Figure 3-6
Box Plots Showing Median (solid line) and Mean (dotted line) Lengths of Grubby Larvae and 25-75th (box), 10-90th (whiskers), and 5-95th (dots) Percentiles

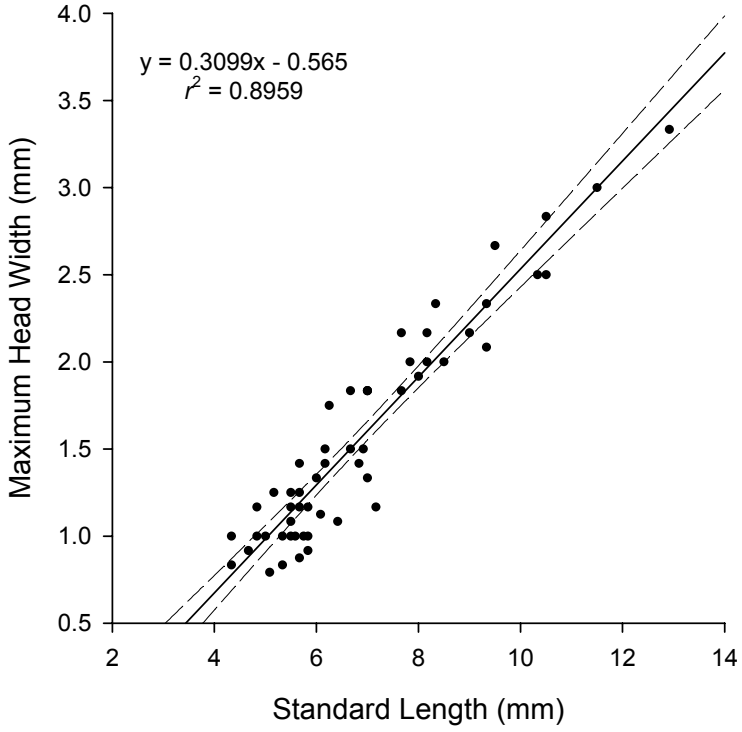

Figure 3-7
Maximum Head Width Plotted Against Standard Length of Grubby Larvae with Regression Line and 95 Percent Confidence Bands

Sand Lance

Sand lance *(Ammodytes americanus)* were the most abundant larvae, representing 51 percent of all larvae collected. Results of the GLM showed that intake type (test vs. control) had a significant effect on sample density ($p<0.05$). Neither slot velocity nor intake type/slot velocity interaction had a significant effect on sample density. However, the intake type/slot width interaction was significant ($p<0.05$), suggesting that the difference between test and control densities was dependent on slot width. This is illustrated on Figure 3-8 which shows a large difference between test and control densities for the 0.5 mm screen, but not the 1.0 mm screen. Post-hoc comparisons showed that the differences between test and control densities were significant for trials with the 0.5 mm screen ($p<0.05$), but not for the 1.0 mm screen ($p>0.05$). In addition, entrainment densities in the 0.5 mm screen samples were significantly less than in the 1.0 mm samples ($p<0.05$).

The covariate of ambient ichthyoplankton density was found to be a significant predictor of sample density ($p<0.05$). Ambient velocity also had a significant effect on sample density ($p<0.05$). For both control and test samples, and for all test conditions, larval densities tended to increase as ambient velocity increased (Figure 3-9). Unlike the results for grubby, the intake type/ambient velocity interaction was not significant ($p>0.05$). This suggests that ambient velocity did not influence the difference between test and control densities. However, the low, albeit insignificant, p-value as well as the trends displayed on Figure 3-9, indicate that densities increased at a slower rate with ambient velocity for the 0.5 mm screen trials. In contrast, the densities of test and control samples from the 1.0 mm screen were similar and increased with ambient velocity in a similar fashion.

The mean densities of sand lance collected in ambient, control, and test samples, and the differences between test and control densities are shown by test condition in Table 3-2 for each length class. Test samples collected through the 0.5 mm screen demonstrated a significant (80 to 93 percent) reduction in entrainment over control samples for all length classes combined. With the exception of the ≥16 mm length class, which was confounded by small sample size, there was a significant difference between the test and control densities of all larvae greater than 5 mm in length. In addition, at a slot velocity of 0.15 m/s, there was a 78 percent difference in the densities of larvae ≤5 mm. While the 0.5 mm screen was effective for nearly all length classes at both slot velocities, there were no significant differences between test and control densities for the 1.0 mm screen, regardless of length class or slot velocity. No larvae ≥16 mm were entrained through the 1.0 mm screen, however insufficient numbers were collected in control samples to demonstrate statistical significance.

Comparison of test and control densities for trials with the 0.5 mm screen showed slightly lower differences at a slot velocity of 0.30 m/s. However, this may be attributable in part to lower control densities at the higher slot velocity rather than higher test densities. For nearly all test conditions, ambient densities were higher than both control and test densities.

To provide a description of larval length distribution, and as another method for evaluating the effect of length on entrainment rates, Figure 3-10 shows the mean lengths of sand lance collected in each type of sample. At both slot velocities, larvae in the 0.5 mm screen samples were significantly smaller than in both control and ambient samples, and were significantly smaller

than in the 1.0 mm screen samples at the higher slot velocity (p<0.008). Larvae in the 1.0 mm screen samples were significantly smaller than in ambient samples at both slot velocities (p<0.008), but were not different from larvae in control samples. Larvae in control samples were significantly smaller than in ambient samples at both slot velocities (p<0.008). Although there were differences in the length distributions based on sample type, length class did not appear to have as much of an effect on differences in sample densities for sand lance. This may be related to the morphology of this species. Head width was highly correlated with body length (r^2=0.85; p<0.05; Figure 3-11). However, the slope of the regression line was relatively low (0.079), indicating that head width only increases slowly with length for this species. The morphology of sand lance can therefore be characterized as elongate and narrow bodied. Based on this relationship, for a length of 8 mm (the median length observed in control samples), the expected head width would be 0.71 mm, which is comparable to the width corresponding to the median length of winter flounder and carp spp., as described below.

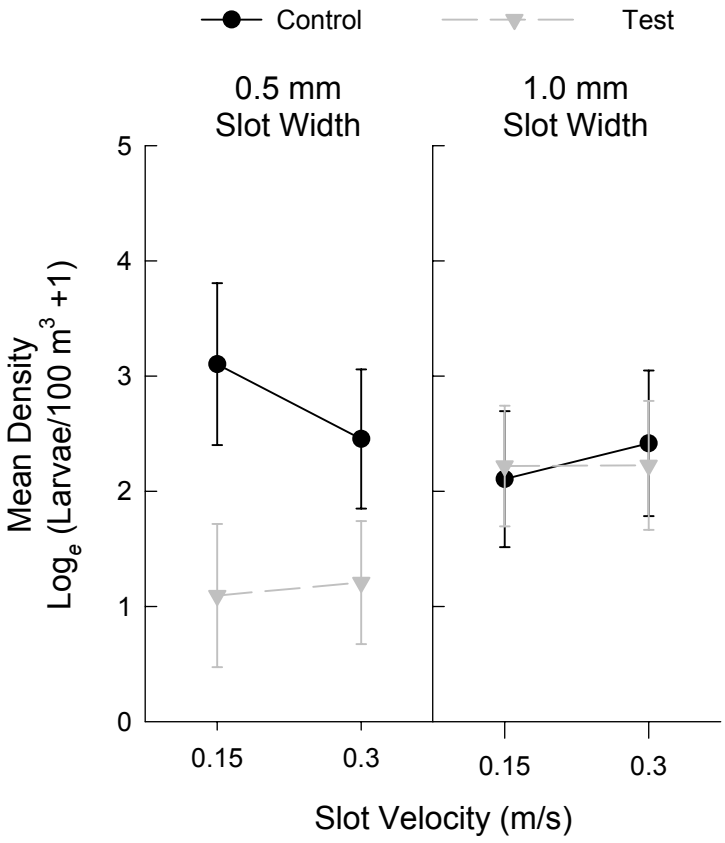

Figure 3-8
Mean Density (log transformed) of Sand Lance Larvae Collected in Control and Test Samples with 95 Percent Confidence Intervals

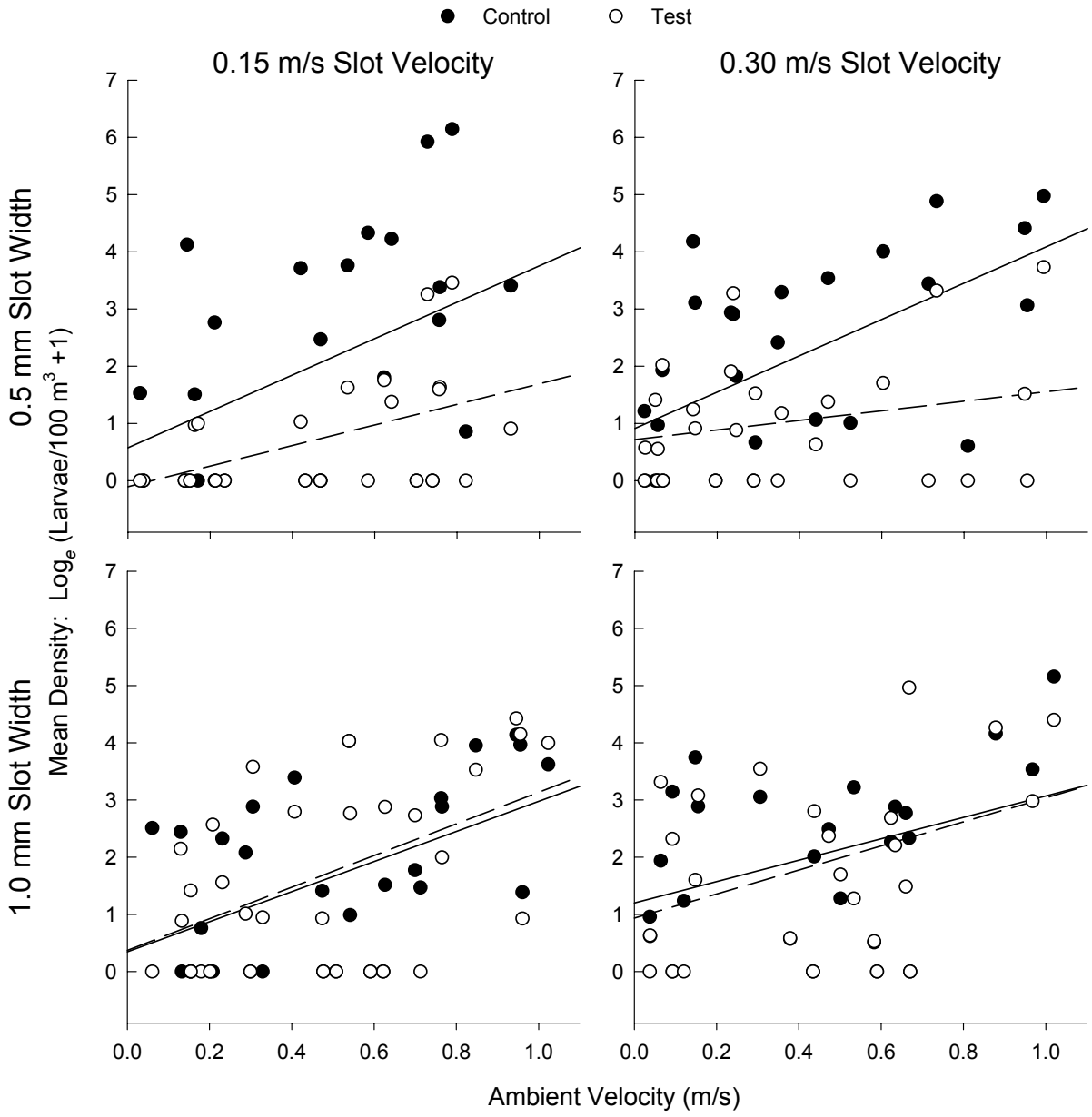

Figure 3-9
Density of Sand Lance Larvae Collected in Control and Test Samples Plotted Against Mean Ambient Velocity with Regression Lines (Solid = Control; Dashed = Test)

Table 3-2
Mean density and standard deviation (SD) of sand lance larvae collected in ambient, control, and test samples during trials with 0.5 and 1.0 mm screens at slot velocities of 0.15 and 0.30 m/s. C-T is the percent difference between test and control densities.[a] Asterisks indicate a statistically significant difference between test and control densities ($p<0.05$).

Slot Width (mm)	Slot Velocity (m/s)	Larval Length (mm)	Mean Number Entrained per 100 m^3 (SD)			C-T Percent Difference (Valid Trials)
			Ambient	Control	Test	
0.5	0.15	≤5	0.0 (0.0)	0.8 (1.7)	0.2 (0.6)	78.6 (6)*
		6-10	57.6 (80.2)	43.6 (102.9)	2.9 (7.5)	93.4 (16)*
		11-15	34.9 (45.0)	4.7 (13.6)	0.1 (0.3)	98.8 (8)*
		≥16	0.7 (1.4)	0.1 (0.5)	0.0 (0.0)	100.0 (2)
		All	91.6 (114.6)	47.5 (112.6)	3.2 (7.5)	93.3 (17)*
	0.30	≤5	0.0 (0.0)	1.1 (3.0)	0.9 (1.9)	15.0 (11)
		6-10	38.5 (56.0)	20.0 (35.9)	4.0 (9.1)	80.0 (20)*
		11-15	28.8 (97.4)	1.3 (2.4)	0.1 (0.2)	95.9 (12)*
		≥16	5.8 (17.4)	0.3 (1.0)	0.0 (0.0)	100.0 (4)
		All	87.5 (134.4)	24.9 (38.9)	4.9 (9.8)	80.2 (23)*
1.0	0.15	≤5	0.0 (0.0)	0.9 (2.1)	1.0 (3.1)	-15.3 (8)
		6-10	41.5 (49.3)	10.3 (16.1)	13.4 (20.0)	-29.8 (23)
		11-15	32.6 (49.8)	1.4 (2.9)	1.1 (3.6)	23.9 (11)
		≥16	7.6 (25.3)	0.2 (1.1)	0.0 (0.0)	N/A[b]
		All	81.8 (89.8)	12.8 (18.8)	15.5 (23.0)	-20.8 (24)
	0.30	≤5	0.0 (0.0)	0.8 (1.7)	0.9 (2.3)	-13.2 (9)
		6-10	61.0 (88.4)	20.0 (40.1)	19.5 (33.3)	2.5 (14)
		11-15	50.1 (51.9)	1.0 (1.6)	1.4 (2.5)	-43.7 (9)
		≥16	29.8 (39.5)	0.2 (0.3)	0.0 (0.0)	100.0 (4)
		All	111.8 (122.1)	19.0 (35.4)	18.6 (33.1)	2.2 (21)

[a] "C-T Percent Difference" is calculated as [(control density minus test density) divided by control density]. Thus, positive values indicate lower densities in test samples.
[b] Insufficient data for meaningful comparison

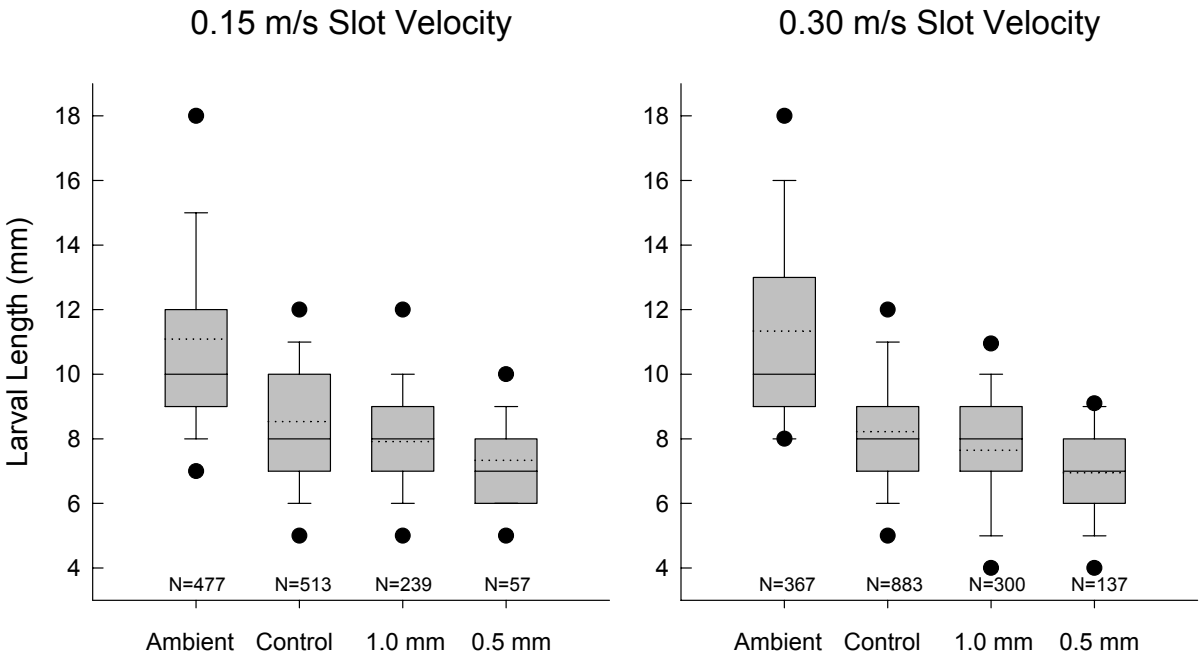

Figure 3-10
Box Plots Showing Median (solid line) and Mean (dotted line) Lengths of Sand Lance Larvae and 25-75th (box), 10-90th (whiskers), and 5-95th (dots) Percentiles

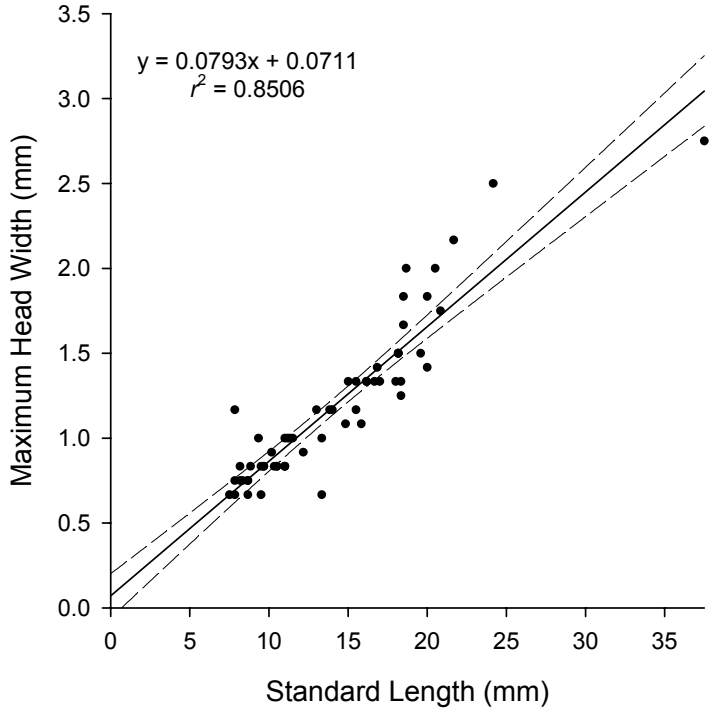

Figure 3-11
Maximum Head Width Plotted Against Standard Length of Sand Lance Larvae with Regression Line and 95 Percent Confidence Bands

Winter Flounder

Winter flounder *(Pseudopleuronectes americanus)* were the second most abundant larvae, representing 34 percent of all larvae collected. Intake type (test vs. control) did not have a significant effect on winter flounder density ($p>0.05$). However, the intake type/slot width interaction was significant ($p<0.05$), indicating that the difference between test and control samples was dependent on slot width. Neither the effect of slot velocity nor the intake type/slot velocity interaction were significant, but the intake type/slot velocity/slot width interaction was significant ($p<0.05$), suggesting that slot velocity may have affected the difference between test and control densities for a certain slot width. Post-hoc comparisons showed that the differences between test and control densities were significant for trials with the 0.5 mm screen at both slot velocities ($p<0.05$), but there was no difference between test and control densities for trials with the 1.0 mm screen at either slot velocity. The relationship between the mean test and control densities is shown for each slot width and slot velocity on Figure 3-12. The significant intake type/slot velocity/slot width interaction is likely due to trials with the 1.0 mm screen which showed higher test densities for 0.15 m/s slot velocity but higher control densities for 0.30 m/s.

The ambient density covariate was found to be a significant predictor of sample density ($p<0.05$). The ambient velocity covariate was found to be significant ($p<0.05$), indicating that ambient velocity had an effect on sample density. However, the intake type/ambient velocity interaction was not significant, suggesting that ambient velocity did not affect the difference between test and control densities. As with grubby and sand lance, the general trend showed that sample densities increased with ambient velocity (Figure 3-13).

The mean densities of winter flounder collected in ambient, control, and test samples, and the differences between test and control densities are shown by test condition in Table 3-3 for each length class. The majority of winter flounder larvae were smaller than 7 mm. As a result, there was insufficient data for the 7-9 and ≥10 mm length classes to offer meaningful comparisons. For the 4-6 mm length class in trials with the 0.5 mm screen, the difference between test and control densities was significant for the 0.15 m/s (76.9 percent) and 0.30 m/s (61.2 percent) slot velocities. At the slower slot velocity, there was also a significant difference for larvae ≤3 mm (33.6 percent). For all lengths combined, the difference between test and control densities was also significant, and was slightly less at a slot velocity of 0.30 m/s than at 0.15 m/s. For trials with the 1.0 mm screen, there were no significant differences between test and control densities for either slot velocity or any length class.

To provide a description of larval length distribution, and as another method for evaluating the effect of length on entrainment rates, Figure 3-14 shows the mean lengths of winter flounder collected in each type of sample. At the lower slot velocity, larvae in both screen samples were significantly smaller than in control and ambient samples ($p<0.008$). At the higher slot velocity, there were no significant differences between larvae in the 1.0 mm screen samples and in ambient or control samples, whereas larvae in the 0.5 mm screen samples were significantly smaller than in the ambient, control, and 1.0 mm screen samples ($p<0.008$). Head width was moderately correlated with body length ($r^2=0.69$; $p<0.05$; Figure 3-7). The slope of the regression line (0.18) was higher than that of sand lance but lower than that of grubby. Thus, the morphology of winter flounder larvae can be characterized as intermediate in terms of length to width ratio. Most importantly though, winter flounder were generally the smallest larvae

collected, which may have had the greatest effect on entrainment rates through the test screens. Based on this relationship, for a length of 4 mm (the median length observed in control samples), the expected head width would be 0.76 mm, which is comparable to the width corresponding to the median length of sand lance and carp spp.

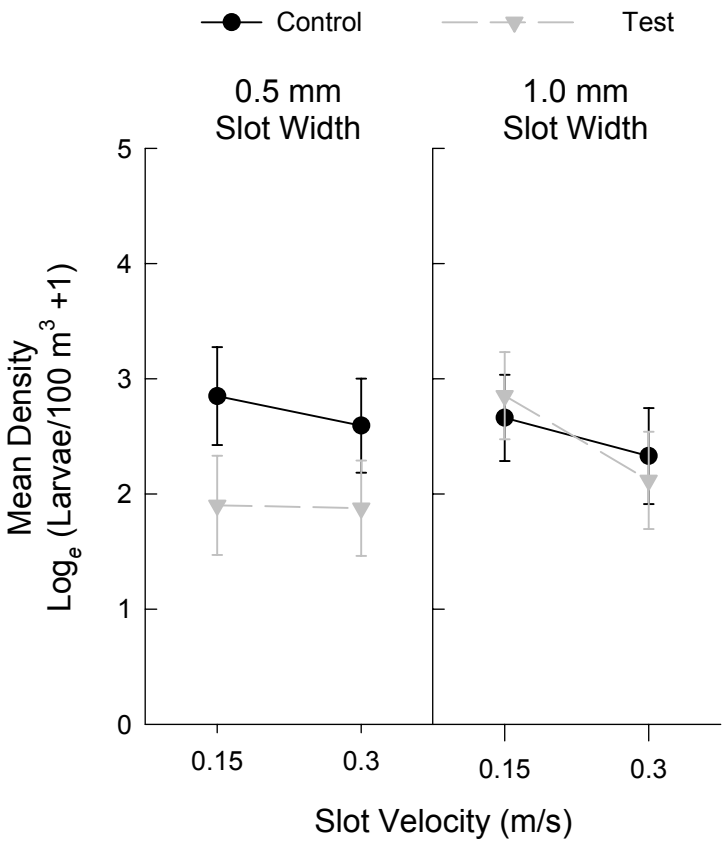

Figure 3-12
Mean Density (log transformed) of Winter Flounder Larvae Collected in Control and Test Samples with 95 Percent Confidence Intervals

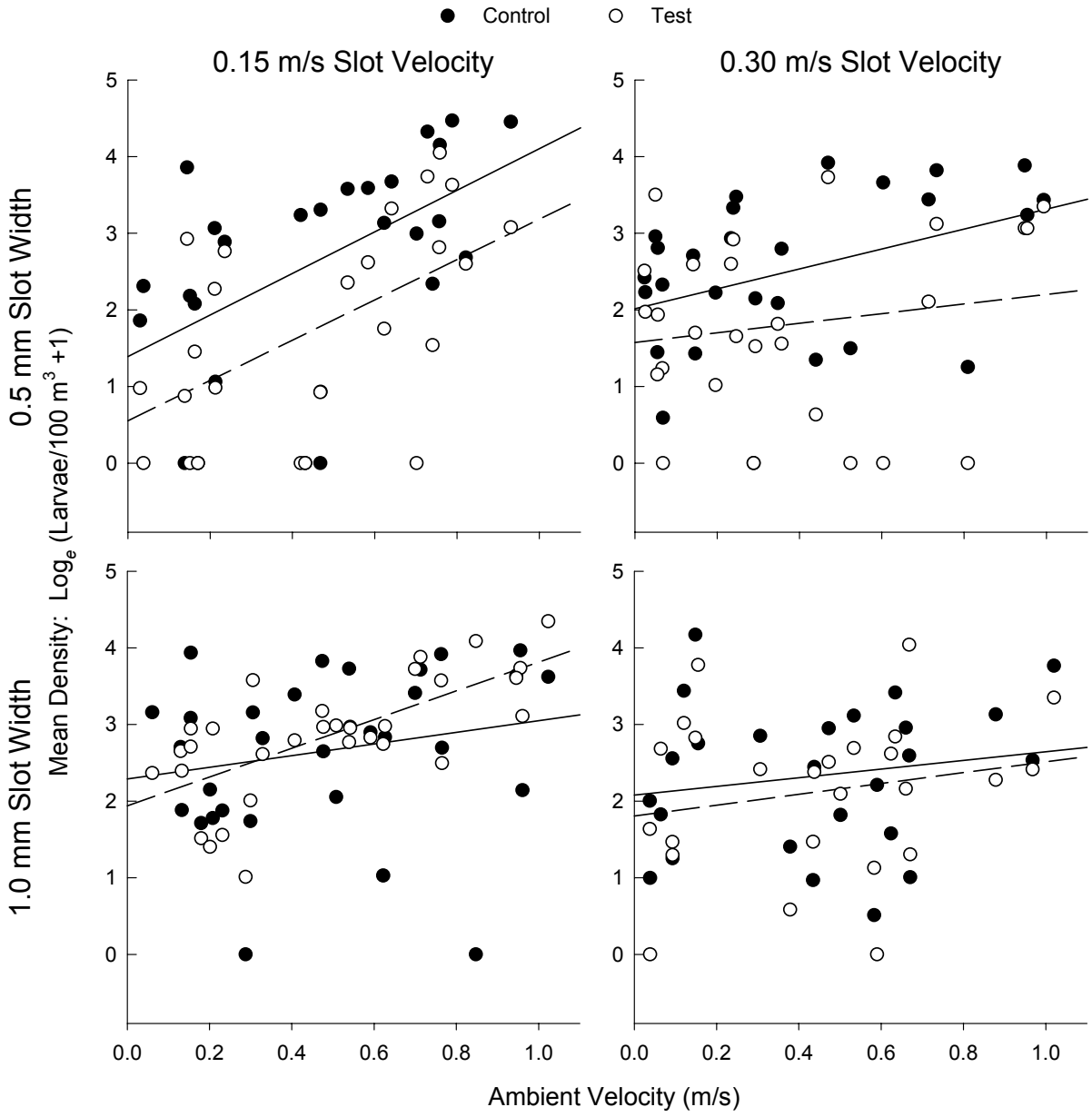

Figure 3-13
Density of Winter Flounder Larvae Collected in Control and Test Samples Plotted Against Mean Ambient Velocity with Regression Lines (Solid = Control; Dashed = Test)

Table 3-3
Mean density and standard deviation (SD) of winter flounder larvae collected in ambient, control, and test samples during trials with 0.5 and 1.0 mm screens at slot velocities of 0.15 and 0.30 m/s. C-T is the percent difference between test and control densities.[a] Asterisks indicate a statistically significant difference between test and control densities (p<0.05).

Slot Width (mm)	Slot Velocity (m/s)	Larval Length (mm)	Mean Number Entrained per 100 m^3 (SD)			C-T Percent Difference (Valid Trials)
			Ambient	Control	Test	
0.5	0.15	≤3	13.5 (12.9)	12.3 (12.0)	8.2 (11.8)	33.6 (24)*
		4-6	16.0 (14.0)	13.4 (18.3)	3.1 (5.4)	76.9 (20)*
		7-9	1.9 (2.3)	0.0 (0)	0.0 (0.0)	N/A[b]
		≥10	0.0 (0.0)	0.0 (0)	0.0 (0.0)	N/A[b]
		All	31.4 (19.5)	25.7 (26.0)	11.3 (14.7)	56.2 (24)*
	0.30	≤3	17.5 (16.9)	6.0 (5.3)	5.3 (5.9)	10.9 (26)
		4-6	45.6 (82.5)	11.4 (12.4)	4.4 (6.6)	61.2 (24)*
		7-9	5.0 (13.5)	0.0 (0.2)	0.0 (0.2)	-30.6 (2)
		≥10	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	N/A[b]
		All	77.0 (89.9)	17.4 (15)	9.8 (11.0)	43.8 (26)*
1.0	0.15	≤3	30.0 (22.0)	10.1 (8.8)	12.0 (9.0)	-18.6 (30)
		4-6	34.5 (19.8)	10.0 (10.2)	9.4 (12.0)	5.8 (31)
		7-9	3.1 (8.0)	0.3 (1.1)	0.3 (1.5)	-16.4 (4)
		≥10	0.1 (0.4)	0.0 (0.0)	0.0 (0.0)	N/A[b]
		All	67.7 (29.8)	20.4 (16.2)	21.7 (17.0)	-6.7 (31)
	0.30	≤3	18.2 (16.5)	5.9 (6.1)	4.3 (4.9)	26.6 (24)
		4-6	14.7 (12.6)	9.0 (8.8)	8.0 (11.0)	11.0 (22)
		7-9	0.7 (1.4)	0.2 (0.6)	0.1 (0.3)	44.2 (4)
		≥10	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	N/A[b]
		All	33.3 (20.6)	14.5 (14.7)	12.1 (13.1)	16.9 (25)

[a] "C-T Percent Difference" is calculated as [(control density minus test density) divided by control density]. Thus, positive values indicate lower densities in test samples.
[b] Insufficient data for meaningful comparison

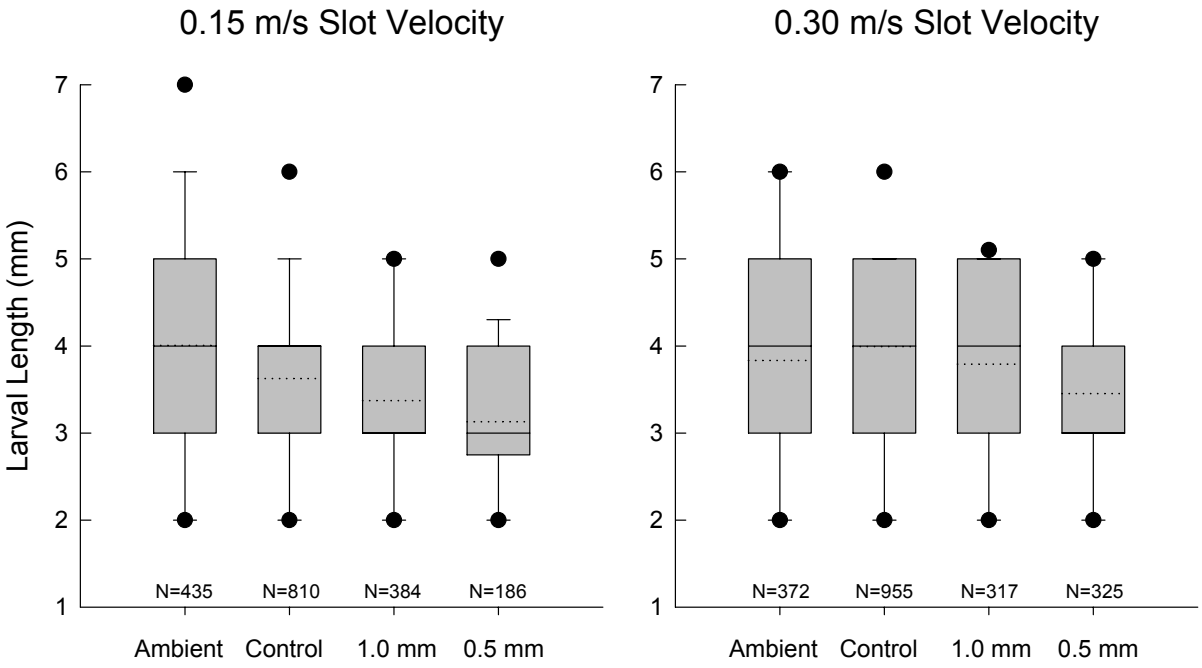

Figure 3-14
Box Plots Showing Median (solid line) and Mean (dotted line) Lengths of Winter Flounder Larvae and 25-75th (box), 10-90th (whiskers), and 5-95th (dots) Percentiles

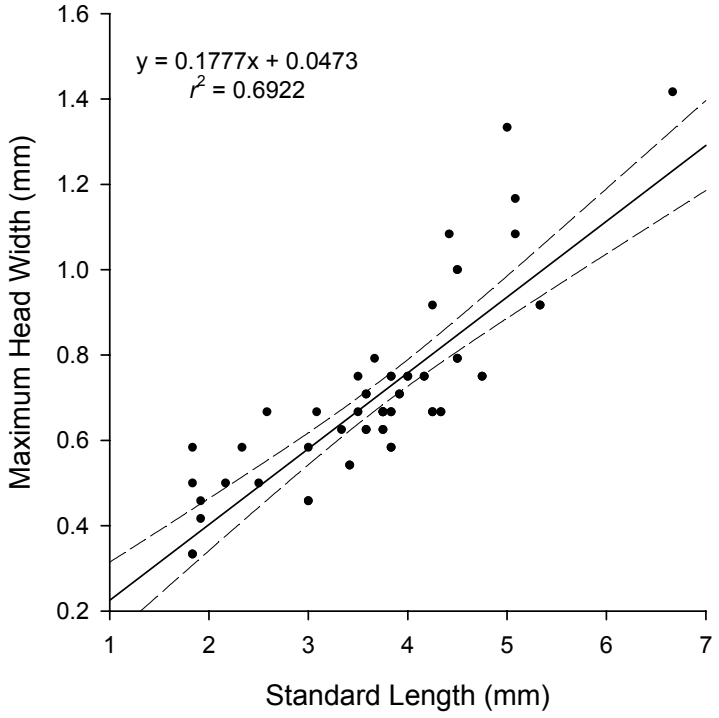

Figure 3-15
Maximum Head Width Plotted Against Standard Length of Winter Flounder Larvae with Regression Line and 95 Percent Confidence Bands

All Species

For the purposes of evaluating entrainment of all species combined, unidentifiable larvae, the three dominant larvae described above, and all other species collected were included in a comprehensive analysis. The relative abundance and total numbers of each species collected are presented on Figure 3-16. Because sand lance were the most abundant species (51 percent), they presumably contribute the most to the analyses below, followed by winter flounder, and then grubby. Intake type (test vs. control) did not have a significant effect on larval density. However, the intake type/slot width interaction was significant ($p<0.05$), indicating that a significant difference between test and control densities did occur, but was dependent on slot width. Neither slot velocity nor the intake type/slot velocity interaction were significant factors. Post-hoc comparisons showed that differences between test and control densities were significant for trials with the 0.5 mm screen ($p<0.05$) but not the 1.0 mm screen (Figure 3-17).

The ambient density covariate was found to be a significant predictor of sample density ($p<0.05$). The ambient velocity covariate was found to be significant ($p<0.05$), indicating that ambient velocity had an effect on sample density. For both control and test samples, and for all test conditions, larval densities showed an increasing trend as ambient velocity increased (Figure 3-18). However, the intake type/ambient velocity interaction was not significant ($p>0.05$), indicating that the difference between test and control densities was not influenced by ambient velocity.

The mean densities of larvae collected in ambient, control, and test samples are shown by test condition in Table 3-4 for each length class. As shown previously, there is considerable morphological variation among species and using length classifications that are not species-specific can be misleading. Nonetheless, the combined species data can be used to show general trends by length class. With the exception of the ≤3 mm length class at a slot velocity of 0.30 m/s, test densities for each length class were significantly lower than control densities for trials with the 0.5 mm screen. Again, with the exception of larvae ≤3mm, for a given length class the percent difference between test and control densities was a maximum of 10 percent less at the higher slot velocity when compared to the corresponding data for the lower slot velocity. For all lengths and all species combined, test densities were 82.2 and 72.4 percent less than control densities at a slot velocity of 0.15 m/s and 0.30 m/s, respectively.

In contrast, for trials with the 1.0 mm screen, there were no significant differences between test and control densities, regardless of length class or slot velocity. Although mean control densities were generally higher than test densities, either variation in the data or the low magnitude of this difference rendered the results statistically insignificant. For nearly all test conditions and length classes, ambient densities were higher than both control and test densities.

Figure 3-19 shows box plots of larval lengths for each sample type. For trials with both slot velocities, larvae collected from ambient samples were significantly larger than all other sample types ($p<0.008$). Control larvae were significantly larger than larvae collected through both slot widths ($p<0.008$), and larvae collected through 1.0 mm slot width were significantly larger than those collected through the 0.5 mm slot width ($p<0.008$).

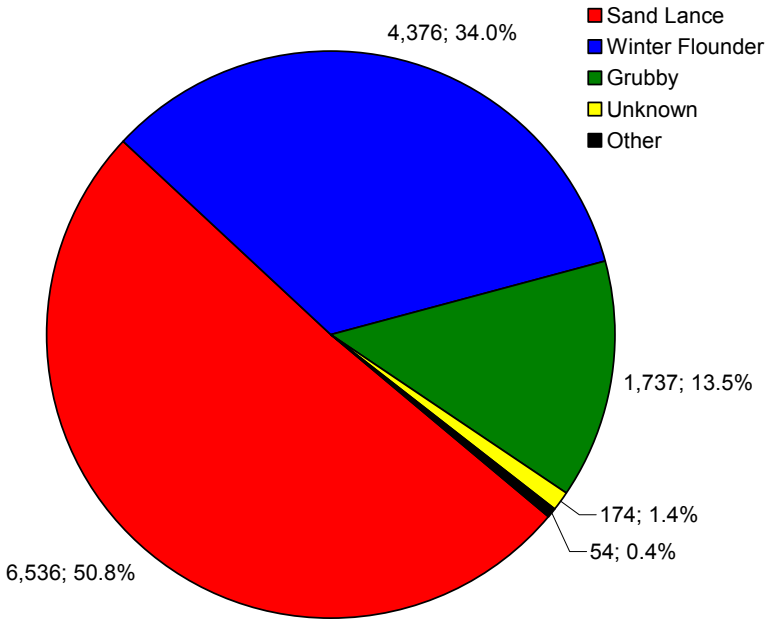

Figure 3-16
Species Composition of Samples Collected from the Sakonnet River Showing Number Collected and Percent Contribution ("Other" includes Clupeidae, Cottidae, Labridae, and Pholidae).

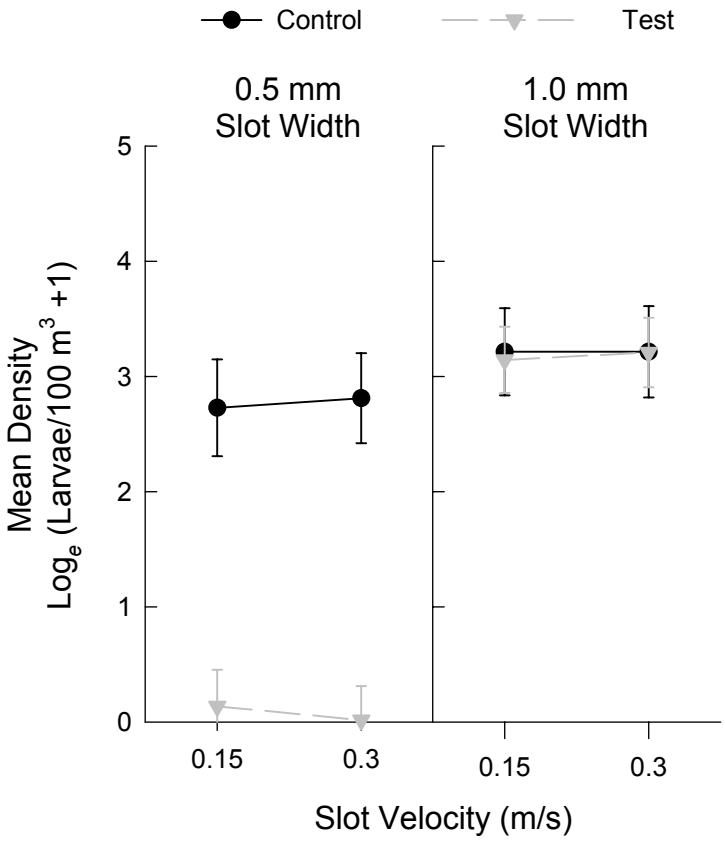

Figure 3-17
Mean Density (log transformed) of Larvae (all species) Collected in Control and Test Samples with 95 Percent Confidence Intervals

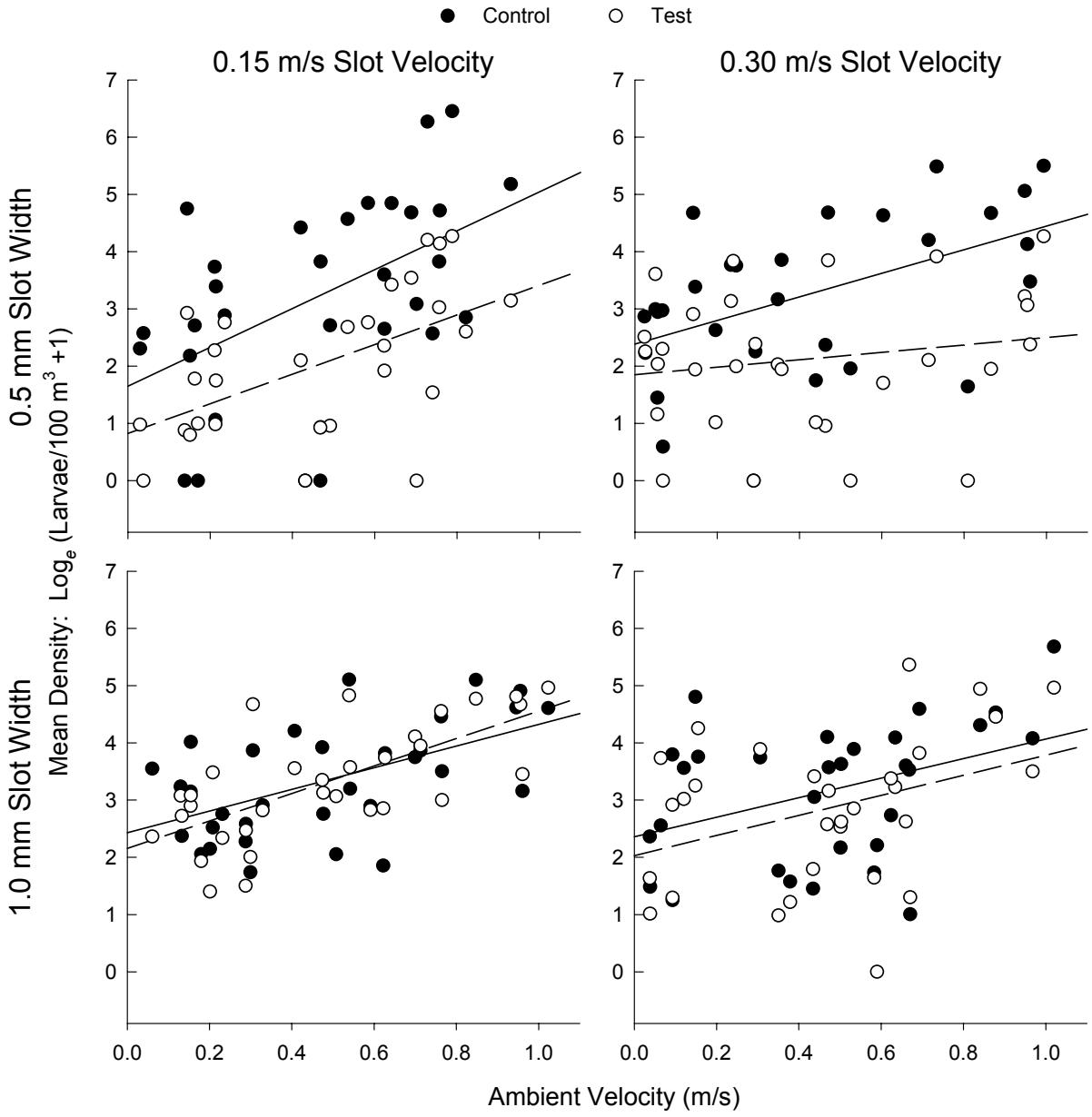

Figure 3-18
Density of Larvae (all species) Collected in Control and Test Samples Plotted Against Mean Ambient Velocity with Regression Lines (Solid = Control; Dashed = Test)

Table 3-4
Mean density and standard deviation (SD) of larvae (all species) collected in ambient, control, and test samples during trials with 0.5 and 1.0 mm screens at slot velocities of 0.15 and 0.30 m/s. C-T is the percent difference between test and control densities.[a] Asterisks indicate a statistically significant difference between test and control densities (p<0.05).

Slot Width (mm)	Slot Velocity (m/s)	Larval Length (mm)	Mean Number Entrained per 100 m^3 (SD)			C-T Percent Difference (Valid Trials)
			Ambient	Control	Test	
0.5	0.15	≤3	13.5 (11.7)	12.7 (12.2)	7.7 (11.1)	39.2 (28)*
		4-6	32.7 (28.6)	24.6 (30.6)	4.6 (7.2)	81.2 (25)*
		7-9	39.8 (56.4)	28.1 (69.5)	1.7 (5.3)	93.8 (18)*
		≥10	49.5 (70.4)	15.8 (46.0)	0.2 (0.8)	98.8 (13)*
		All	135.5 (133.5)	81.1 (144.8)	14.5 (19.6)	82.2 (29)*
	0.30	≤3	18.1 (16.4)	6.1 (5.5)	5.0 (5.7)	17.2 (29)
		4-6	52.1 (82.0)	23.8 (29.5)	6.4 (9.1)	73.2 (27)*
		7-9	30.0 (45.0)	17.3 (28.3)	2.6 (6.6)	85.2 (23)*
		≥10	88.6 (177.5)	5.3 (8.1)	0.1 (0.6)	97.2 (19)*
		All	210.5 (194.7)	52.6 (65.2)	14.5 (17.7)	72.4 (29)*
1.0	0.15	≤3	30.2 (21.9)	11.7 (9.8)	12.7 (9.5)	-8.4 (31)
		4-6	41.6 (18.6)	18.2 (21.2)	16.2 (20.0)	10.7 (32)
		7-9	32.9 (43.2)	10.0 (15.8)	10.1 (16.3)	-0.3 (23)
		≥10	61.7 (79.1)	3.6 (7.7)	3.1 (8.9)	14.5 (16)
		All	166.4 (96.8)	43.5 (44.7)	42.2 (42.1)	2.9 (32)
	0.30	≤3	18.8 (15.6)	5.8 (6.2)	4.7 (5.0)	18.9 (29)
		4-6	18.0 (15.7)	18.5 (24.4)	15.1 (22.1)	18.5 (28)
		7-9	41.2 (79.1)	14.3 (27.8)	12.4 (23.8)	13.0 (24)
		≥10	75.1 (89.1)	3.7 (4.1)	2.8 (5.3)	23.1 (25)
		All	153.2 (147.0)	43.3 (56.5)	35.7 (49.3)	17.6 (30)

[a] "C-T Percent Difference" is calculated as [(control density minus test density) divided by control density]. Thus, positive values indicate lower densities in test samples.

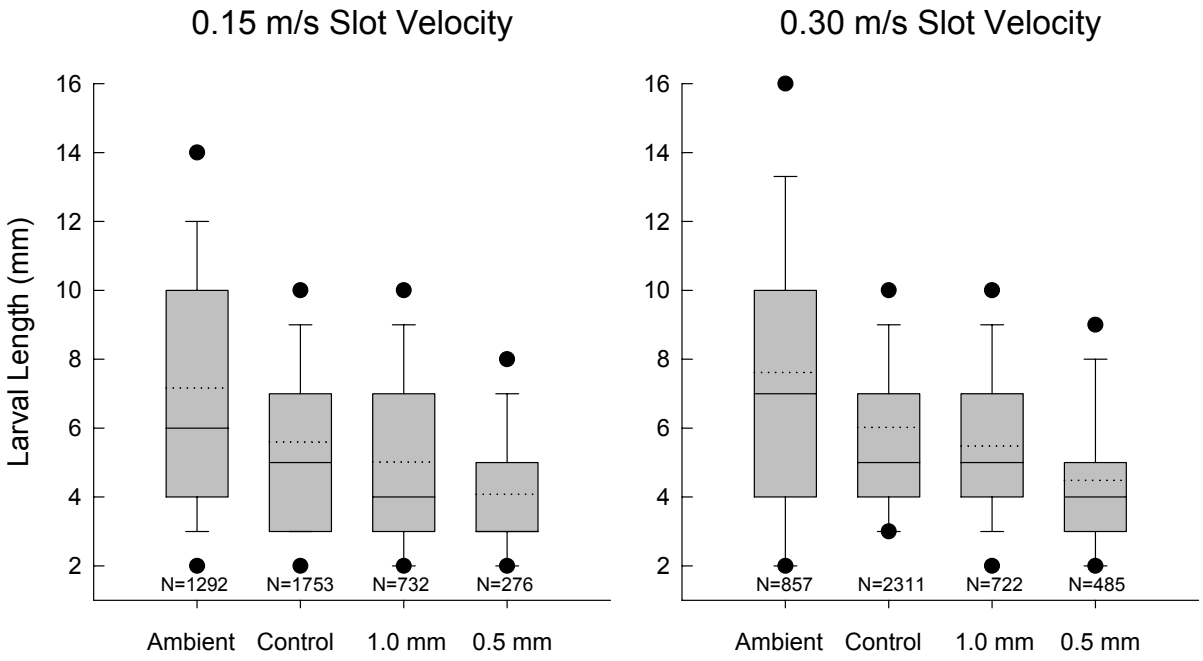

Figure 3-19
Box Plots Showing Median (solid line) and Mean (dotted line) Lengths of Larvae (all species) and 25-75th (box), 10-90th (whiskers), and 5-95th (dots) Percentiles

Eggs

Although the eggs collected from the Sakonnet River were not taxonomically identified, unpublished data from previous sampling in the vicinity of the test facility indicate that, during April and May, the dominant egg species are fourbeard rockling *(Enchelyopus cimbrius)* and Labrid species (i.e., tautog or cunner). There was a significant difference in entrainment density between test and control samples ($p<0.05$). The intake type/slot width interaction was also significant ($p<0.05$), indicating that the difference between test and control densities was dependent on slot width. Slot velocity did not have a significant effect on sample density ($p>0.05$), and did not have an effect on the difference between test and control densities ($p>0.05$). Post-hoc comparisons revealed that the differences between test and control densities were significant for trials with the 0.5 mm screen ($p<0.05$), but not for the 1.0 mm screen trials (Figure 3-20).

Unlike the results for larvae in the previous sections, ambient velocity did not have a significant effect on the sample density for eggs. The intake type/ambient velocity interaction was also insignificant, indicating that the difference between egg densities in test and control samples was unaffected by ambient velocity (Figure 3-21).

The mean densities of eggs collected in ambient, control, and test samples are shown by test condition in Table 3-5. The differences between control and test sample densities are also shown and are indicated where significant. Because data were analyzed using the GLM, significance reflects the results of post hoc comparisons of the log transformed densities. There was a difference of 92.5 percent at a slot velocity of 0.15 m/s and a 99.9 percent difference at a slot

velocity of 0.30 m/s. For trials with the 1.0 mm screen, there was a difference of 27.0 percent between test and control densities at a 0.15 m/s slot velocity, and a difference of 7.7 percent at 0.30 m/s. With the exception of trials with the 1.0 mm slot width at a slot velocity of 0.30 m/s, the mean density of ambient samples was greater than test samples. Except for trials with the 0.5 mm screen at a slot velocity of 0.15 m/s, mean densities were generally comparable in ambient and control samples.

To characterize the size distribution of eggs and to compare egg sizes among sample types, the diameters of egg subsamples were measured in selected ambient and test samples (Figure 3-22). The overall mean egg diameter was 0.88 mm. A comparison could not be made between the ambient and test samples selected for 0.5 mm slot width trials because no eggs were present in the selected test samples. For trials with a slot width of 1.0 mm, ambient sample eggs (mean = 0.90 mm) were significantly larger (p<0.05) than test sample eggs (mean = 0.86 mm).

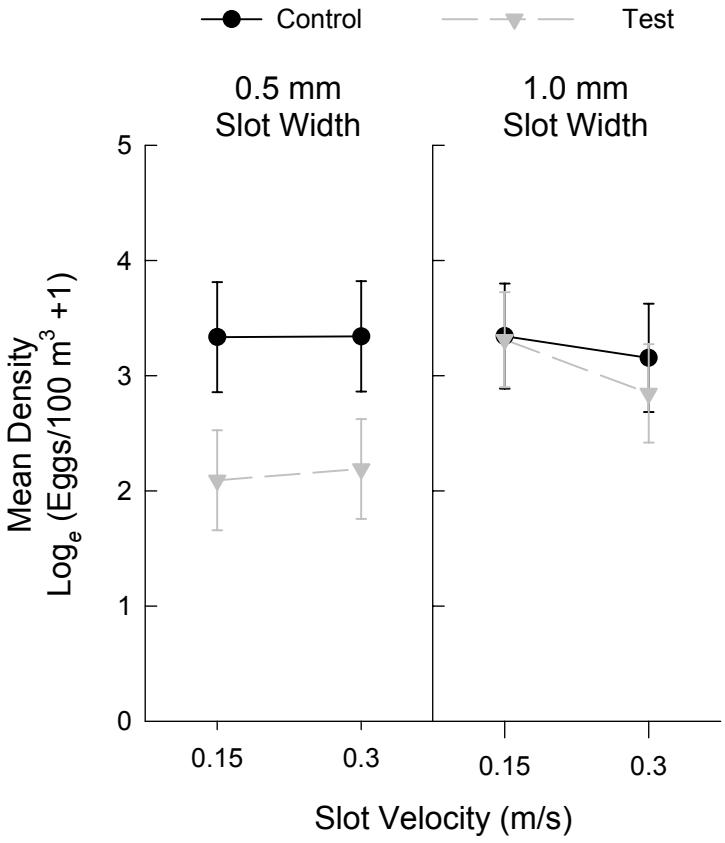

Figure 3-20
Mean Density (log transformed) of Eggs Collected in Control and Test Samples with 95 Percent Confidence Intervals

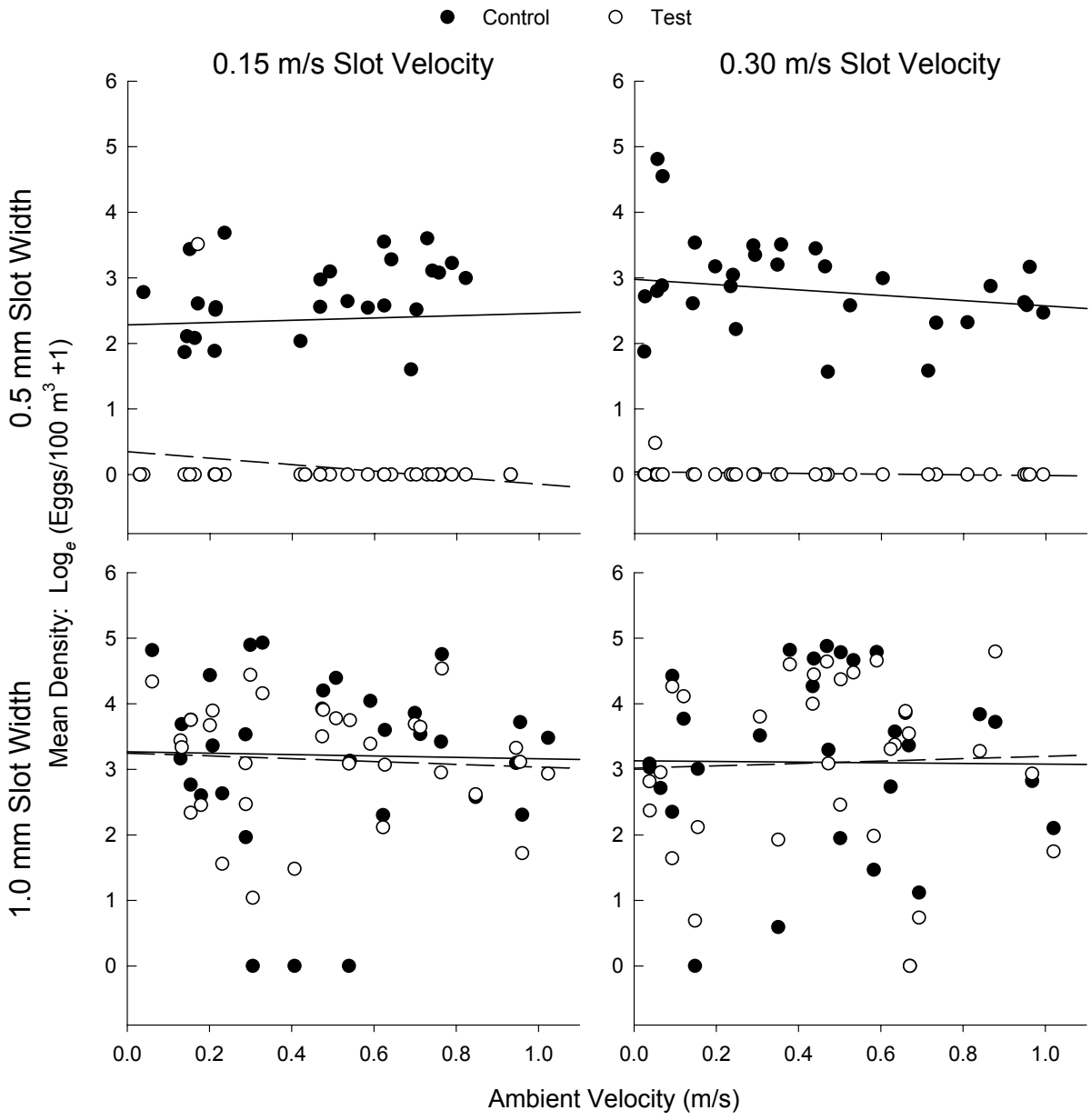

Figure 3-21
Density of Eggs Collected in Control and Test Samples Plotted Against Mean Ambient Velocity (Solid = Control; Dashed = Test)

Table 3-5
Mean density and standard deviation (SD) of eggs collected in ambient, control, and test samples during trials with 0.5 and 1.0 mm screens at slot velocities of 0.15 and 0.30 m/s. C-T is the percent difference between test and control densities.[a] Asterisks indicate a statistically significant difference between test and control densities (p<0.05).

Slot Width (mm)	Slot Velocity (m/s)	Mean Number Entrained per 100 m^3 (SD)			C-T Percent Difference (Valid Trials)
		Ambient	Control	Test	
0.5	0.15	14.2 (12.1)	14.5 (10.8)	1.1 (5.9)	92.5 (26)*
	0.30	44.0 (55.6)	22.8 (25.0)	0.0 (0.1)	99.9 (30)*
1.0	0.15	60.6 (42.2)	42.0 (39.0)	30.6 (23.2)	27.0 (32)
	0.30	38.2 (42.9)	42.9 (42.8)	39.6 (37.1)	7.7 (29)

[a] "C-T Percent Difference" is calculated as [(control density minus test density) divided by control density]. Thus, positive values indicate lower densities in test samples.

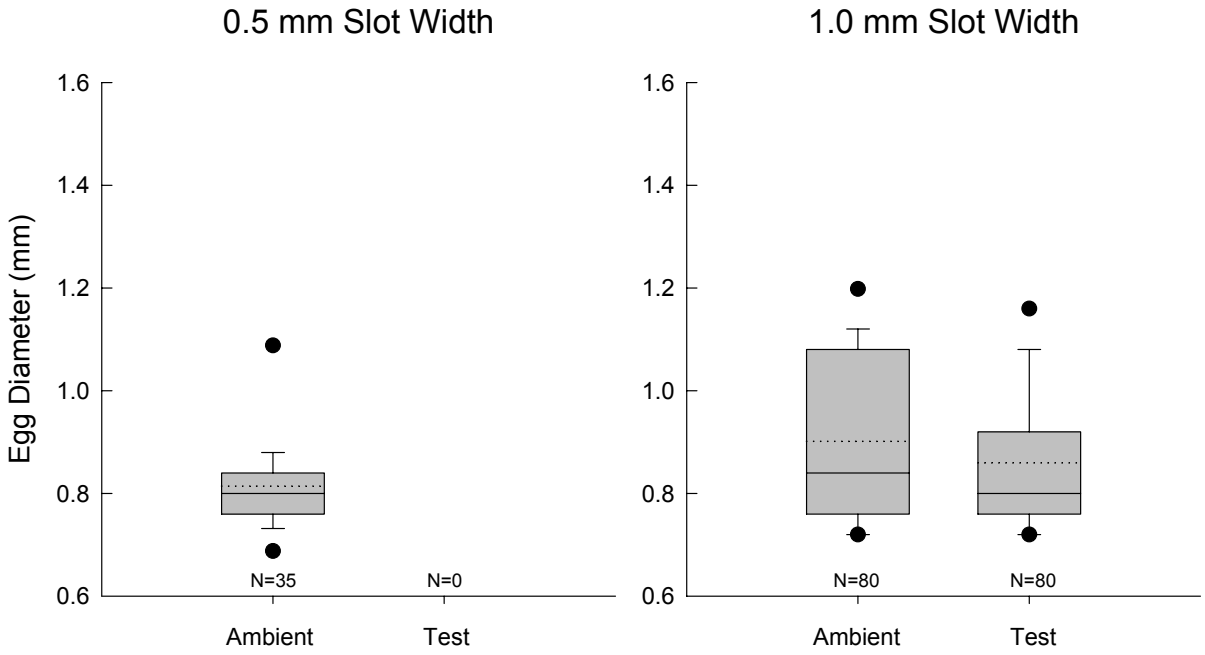

Figure 3-22
Box Plots Showing Median (solid line) and Mean (dotted line) Egg Diameter and 25-75th (box), 10-90th (whiskers), and 5-95th (dots) Percentiles for Eggs Collected from the Sakonnet River

4
FRESHWATER TESTING

Test Site

The mouth of the Portage River, in Port Clinton, Ohio, was selected as the site for freshwater testing (Figure 4-1). During the selection process, review of relevant literature and communication with natural resource agency biologists and university researchers indicated that the western basin of Lake Erie has among the highest concentrations of ichthyoplankton in the Great Lakes and Northeast regions. Unpublished data showed peak larval densities in 1996 ranging from 11 to 12,829 per 100 m^3 from May through June (S. Ludsin, Great Lakes Environmental Research Laboratory). Samples were dominated by *Morone* species (white bass and white perch), clupeid species (alewife and gizzard shad), yellow perch, and cyprinid species. Although the highest densities were found in Maumee Bay and Sandusky Bay, the Portage River is located between these two water bodies and was believed to have comparable densities. High densities of *Morone* and clupeid species and lower densities of yellow perch and cyprinids were expected in the Portage River.

The test site was located at Brands' Marina (41° 30' 57"N, 82° 56' 46"W), roughly 600 m upstream of Lake Erie. The river was roughly 30 m wide at this point and offered more protection from wind and surf than any locations seen in Sandusky Bay or Maumee Bay. Although the river was relatively shallow, the test facility was situated at one of the deepest points in the river, with an estimated depth of approximately 2.4 m. In addition, the site was near a constriction in the river which resulted in relatively high water velocities compared to adjacent areas, ranging from 0 to 0.35 m/s (mean = 0.06 m/s). The test facility was positioned at the end of a pier to facilitate sampling in an area nearer to the middle of the river (Figure 4-2). According to local biologists, extensive spawning and rearing habitat exist upstream of the test site and was expected to supply abundant ichthyoplankton past the test site.

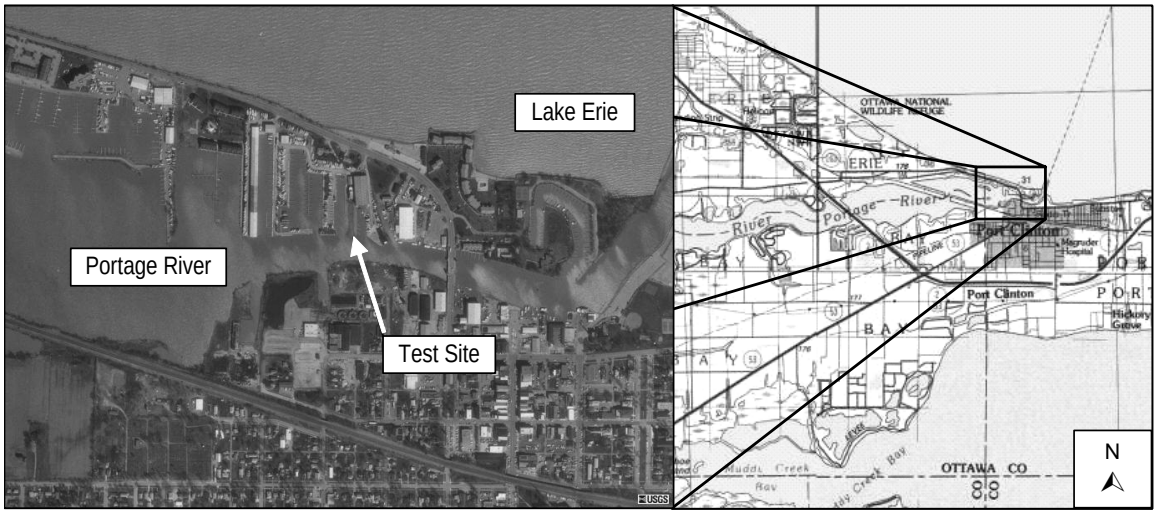

Figure 4-1
Freshwater Test Site in the Portage River

Figure 4-2
Test Facility in Place in the Portage River (facing west)

Methods

In general, the methods employed for freshwater sampling were similar to those used at the estuarine site. Some aspects of sampling differed because of changes to the experimental design or because of practical considerations. However, unless explicitly stated below, the methods were the same as those described in Chapter 3.

Test Procedures

Following completion of the estuarine sampling effort, the test facility was shipped to the Portage River. After a day of preliminary testing, formal testing began on May 15, 2004. Testing was conducted seven days per week until all replicates were completed on June 4, 2004. Prior to the first trial of the day, the intakes were lowered to a depth of 1.2 m (on center) below the water surface. Although the depth at the test site was approximately 2.4 m, the intakes were set at a shallower depth to avoid disturbing any of the fine sediment that characterized the substrate. Because the test site was fairly shallow, it was assumed that fish larvae were uniformly distributed in the water column and did not exhibit extensive diel vertical migrations. For this reason, all testing was conducted during daylight hours.

Unlike the estuarine site, there was no predictable variation in ambient water velocity at the Portage River site. Although water velocity did fluctuate at times, it was typically random and associated with wind conditions. In some instances, winds from the east caused water to flow "upstream" from Lake Erie into the Portage River. However, this was rare and the contours of the river formed an eddy which maintained ambient velocities that were either negligible or approached the test facility from the same direction. Thus, there was no need to reorient the test facility when net water direction changed.

Because the ambient water velocity did not vary predictably, we were unable to target specific ambient velocities in which to sample. To maximize the number of organisms collected, the duration of each trial was extended to last approximately four hours. Initially, the sampling nets were left in place for the entire trial. However, this resulted in higher rates of damaged larvae. To minimize damage, every hour we shut down the pumps, purged the intakes of debris, and rinsed the samples from the nets into labeled buckets, which were then placed in coolers and held until the trial was completed. At the end of the trial each bucket was poured through a 220-µ sieve, which was then rinsed into the corresponding sample jar, labeled a second time, and preserved. Two four-hour trials with the same test screen, but with different slot velocities, were conducted on each day of testing.

Ambient water velocity measurements were taken every 20 minutes over the course of a trial. At the one-hour and three-hour marks, water quality measurements were taken off the side of the test facility. After the two-hour mark, an ambient ichthyoplankton sample was collected by towing the plankton net 20 m behind a johnboat for 4 minutes. The average volume sampled was 60 m^3. Prior to and during the hourly purge of the intakes, an underwater video camera was used to record images of the test screen in an attempt to quantify debris loading and impingement. However, high turbidity and poor image quality confounded this effort.

To determine if any organisms were lost during sample preparation, five quality assurance samples were taken using at least 50 randomly selected larvae. Efficiencies ranged from 96 to 100 percent, with an average of 97.6 percent. Collection efficiency tests were also performed three times using at least 50 randomly selected eggs. These efficiencies ranged from 92.3 to 100 percent, with an average of 96.1 percent. Because the collection efficiency was consistently high, and because both the control and test samples were subjected to the same procedures, it was determined that there was not a need to apply a correction factor to density estimates.

In addition to the routine water velocity measurements taken during each trial, detailed mapping of the velocity field in the vicinity of the water intakes was performed twice, at mean ambient velocities of 0.06 and 0.15 m/s. This was done to determine the uniformity of the flow field as it approached the intakes as well as to confirm that the intakes did not hydraulically influence each other during operation.

Sample Analysis

Samples collected from the Portage River were processed in the same manner as those from the Sakonnet River. The same quality control checks were administered and the same sorting and identification procedures were followed. Body length/head width relationships were also calculated for the dominant species of larvae and the diameter of eggs from test and ambient subsamples were measured. However, unlike the Sakonnet River samples, most samples were split at least once because ichthyoplankton densities were typically higher.

Experimental Design

As described in the test procedures, the primary difference in the experimental design for the Portage River effort was the elimination of ambient velocity as a test parameter. Although ambient velocity measurements were still taken, there was insufficient variability to warrant its inclusion in the statistical models. Eliminating ambient velocity as a variable allowed us to reduce the total number of samples collected to 120 to achieve the desired number of 10 replicates. The duration of each trial was also extended to roughly four hours in attempt to maximize the number of larvae collected and minimize between sample variability. In addition, rather than collecting one ambient sample to represent three consecutive trials, we collected one ambient sample for each pair of test and control samples (i.e., each trial).

Data Analysis

Unless otherwise stated, the same approach that was used for the Sakonnet River effort to test for significant experimental parameters was used for analyzing data from the Portage River. The ambient velocity covariate was not used in the GLM, however, ambient ichthyoplankton density was retained as a covariate. Shad was the only larval taxon collected in sufficient numbers to permit analyses with the GLM or comparisons of entrainment rates by length class. Shad larvae were grouped into the same length classes as grubby and winter flounder (≤3, 4-6, 7-9, ≥10 mm). Eggs were collected in sufficient numbers to permit analysis using the GLM. Data for all other species (carp, freshwater drum, and temperate basses) were analyzed by pairwise comparisons of test and control densities for each set of test conditions with the Wilcoxon Matched Pairs test.

Results

During testing, the mean water temperature was 19.8 °C (range 15.9 to 24.3 °C) and the mean dissolved oxygen was 9.6 mg/L. Turbidity was much higher than at the Sakonnet River site, ranging from 10.2 to 94.7 NTU (mean 31.1 NTU). In addition, the amount of suspended debris in the Portage River was noticeably greater, although this was not quantified. Complete water

quality records from the Portage River are provided in Appendix E. The velocity profiles measured in front of the intakes at moderate and high ambient velocities showed no indication of the intakes hydraulically affecting each other (Figure 3-3). At the higher ambient velocity, velocities were slightly lower on the side of the test facility nearest to pier abutment. However, because ambient velocities were typically much lower than 0.15 m/s, it is unlikely that this difference had an effect on entrainment rates.

A total of 15 different species of larval fish were collected in samples from the Portage River. Shad species (Clupeidae) were by far the most abundant (93 percent of all larvae), but sufficient numbers of carp species (*Cyprinus* spp.), freshwater drum, and temperate basses (*Morone* spp.) were collected to offer meaningful species-specific comparisons. The results comparing entrainment rates through the control intake and test screens under the different test conditions are provided below in separate sections for each species, ordered alphabetically. These are followed by the results for eggs. Analyses were also performed for all species of larvae combined. However, because shad comprised such a large proportion of larvae collected, the results for all species combined were essentially the same as those for shad, and were therefore omitted from this report. Along with species collected from the Sakonnet River, estimated yolk-sac larvae, post yolk-sac larvae, and juveniles length ranges for species collected from the Portage River are provided in Appendix A. Raw entrainment data from the Portage River is provided in Appendix C by trial and species.

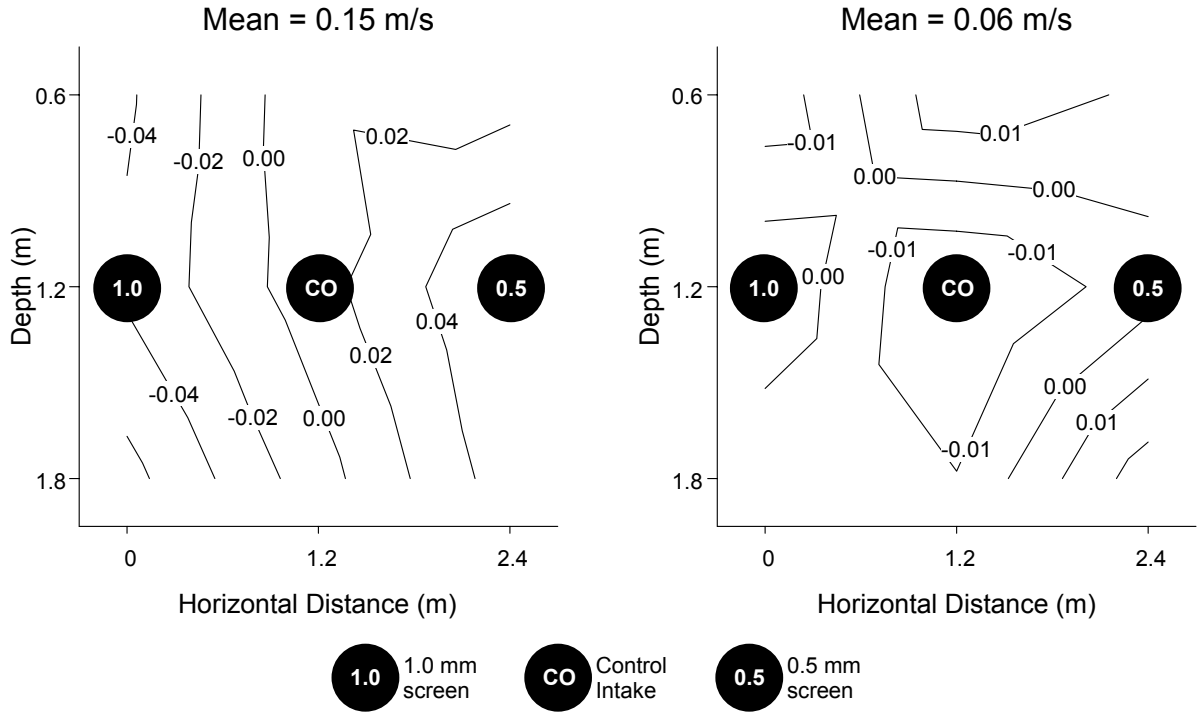

Figure 4-3
Normalized Approach Velocity Profile in Front of Intakes at Portage River Test Site (contour values reflect deviation from the mean approach velocity in m/s)

Carp

Carp *(Cyprinus spp.)* were the third-most abundant larvae, but represented only 1 percent of all larvae collected. Although the majority of carp larvae could only be identified to the genus level, the only species definitively identified and known to be present were common carp *(Cyprinus carpio)*. Carp densities were insufficient to permit analysis using the GLM, or to evaluate entrainment rates by length class. Thus, the analyses for carp were limited to pairwise comparisons between test and control densities using the Wilcoxon Matched Pairs Test for each set of test conditions. Table 4-1 shows the mean densities of carp larvae collected in ambient, control, and test samples by test condition. A significant difference between test and control densities was found for trials with the 1.0 mm screen at a slot velocity of 0.30 m/s ($p<0.05$). However, for all other test conditions, there were no significant differences between test and control densities. Considering the effectiveness of the 0.5 mm screen for even small larvae in the Sakonnet River, the lack of detectable differences for carp is likely attributable to low densities and patchy distribution. This explanation is also supported by the low densities seen in ambient samples.

Figure 4-4 shows box plots of carp lengths for each sample type. At a slot velocity of 0.15 m/s, there were no significant differences in length based on sample type. However, this analysis was likely hindered by low sample sizes. At a slot velocity of 0.30 m/s, larvae from ambient samples were significantly larger than those from 1.0 mm and 0.5 mm slot width samples ($p<0.083$). Again, however, this is based on a small sample size for the ambient sample. There were no significant length differences between control and test samples with either screen.

A moderate correlation was found between the length and maximum head width of carp larvae ($r^2=0.50$; $p<0.05$; Figure 4-5). Based on this relationship, for a length of 5 mm (the median length observed in control samples), the expected head width would be 0.76 mm, which is comparable to the width corresponding to the median length of sand lance and winter flounder.

Table 4-1
Mean density and standard deviation (SD) of carp spp. larvae collected in ambient, control, and test samples during trials with 0.5 and 1.0 mm screens at slot velocities of 0.15 and 0.30 m/s. C-T is the percent difference between test and control densities.[a] Asterisks indicate a statistically significant difference between test and control densities ($p<0.05$).

Slot Width (mm)	Slot Velocity (m/s)	Mean Number Entrained per 100 m^3 (SD)			C-T Percent Difference (Valid Trials)
		Ambient	Control	Test	
0.5	0.15	0.3 (0.9)	2.2 (5.6)	2.7 (7.2)	-22.1 (7)
	0.30	0.0 (0.0)	1.5 (2.9)	1.1 (1.5)	22.3 (6)
1.0	0.15	3.6 (7.4)	1.3 (2.5)	2.1 (3.7)	-65.5 (6)
	0.30	12.4 (25.2)	6.0 (9.3)	2.7 (5.1)	54.3 (7)*

[a] "C-T Percent Difference" is calculated as [(control density minus test density) divided by control density]. Thus, positive values indicate lower densities in test samples.

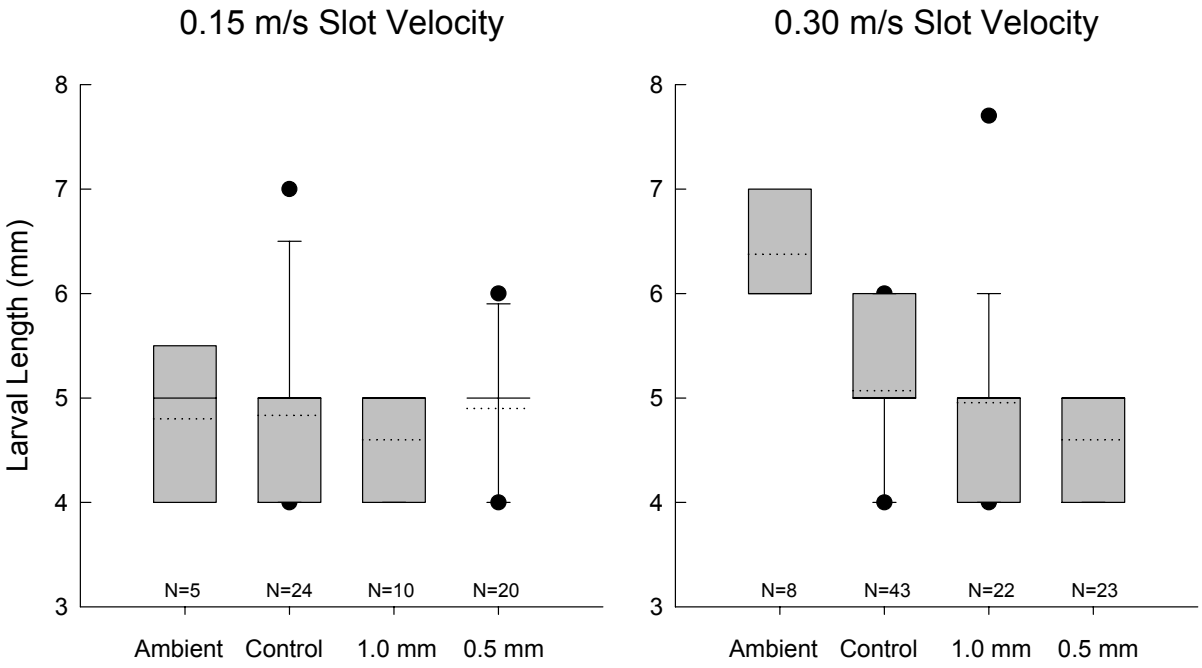

Figure 4-4
Box Plots Showing Median (solid line) and Mean (dotted line) Lengths of Carp Larvae and 25-75th (box), 10-90th (whiskers), and 5-95th (dots) Percentiles

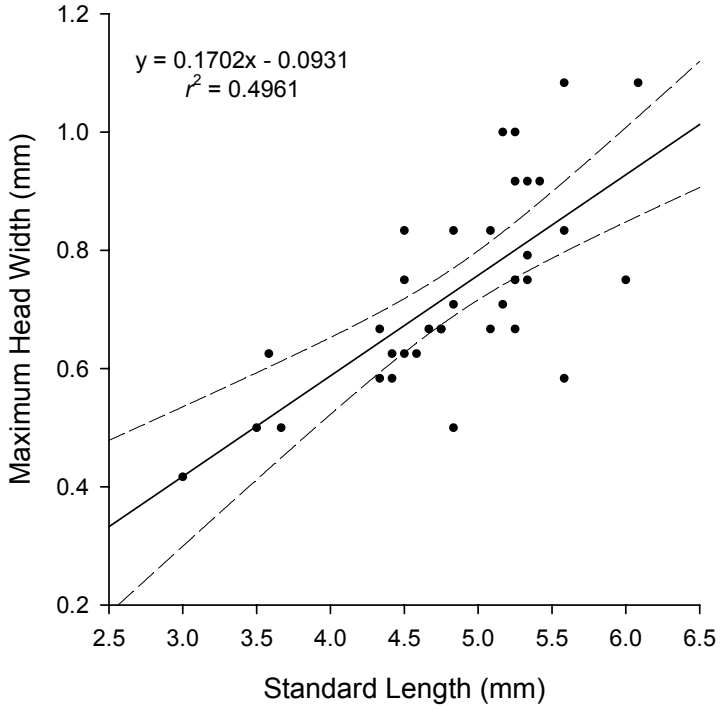

Figure 4-5
Maximum Head Width Plotted Against Standard Length of Carp Larvae with Regression Line and 95 Percent Confidence Bands

Freshwater Drum

Freshwater drum *(Aplodinotus grunniens)* were the second most abundant larvae, representing 3 percent of all larvae collected. However, densities were insufficient to permit analysis using the GLM, or to evaluate entrainment rates by length class. Thus, analyses were limited to pairwise comparisons between test and control densities for each set of test conditions using the Wilcoxon Matched Pairs Test. Table 4-2 shows the mean densities of freshwater drum larvae collected in ambient, control, and test samples by test condition. For all test conditions, there were no significant differences between test and control densities. However, for trials with the 0.5 mm screen, the percent difference between test and control densities was high (>95 percent), and the lack of significance is likely related to the low number of valid trials (n=4). There were even fewer valid trials with the 1.0 mm screen (n≤2), which confounded any meaningful results. As described in the Data Analysis section, the validity of a trial was dependent in part on the presence of larvae in either the control or test sample. Thus, a large number of invalid trials can be attributed to low densities and/or patchy distribution of freshwater drum larvae near the test facility.

Figure 4-6 shows box plots of freshwater drum lengths for each sample type. There were no differences in larval lengths between sample types at either slot velocity. Again, however, the lack of length differences may be related to small sample sizes. Based on subsamples of freshwater drum larvae, no correlation was found between length and maximum head width (r^2=0.03; p>0.05).

Table 4-2
Mean density and standard deviation (SD) of freshwater drum larvae collected in ambient, control, and test samples during trials with 0.5 and 1.0 mm screens at slot velocities of 0.15 and 0.30 m/s. C-T is the percent difference between test and control densities.[a] Asterisks indicate a statistically significant difference between test and control densities (p<0.05).

Slot Width (mm)	Slot Velocity (m/s)	Mean Number Entrained per 100 m^3 (SD)			C-T Percent Difference (Valid Trials)
		Ambient	Control	Test	
0.5	0.15	1.6 (4.2)	2.5 (5.5)	0.1 (0.2)	96.4 (4)
	0.30	43.1 (131.5)	14.2 (36.4)	0.6 (1.6)	95.9 (4)
1.0	0.15	19.7 (52.0)	0.0 (0.0)	0.1 (0.3)	N/A[b]
	0.30	199.3 (549.6)	9.9 (19.9)	2.8 (5.5)	71.7 (2)

[a] "C-T Percent Difference" is calculated as [(control density minus test density) divided by control density]. Thus, positive values indicate lower densities in test samples.
[b] Insufficient data for meaningful comparison

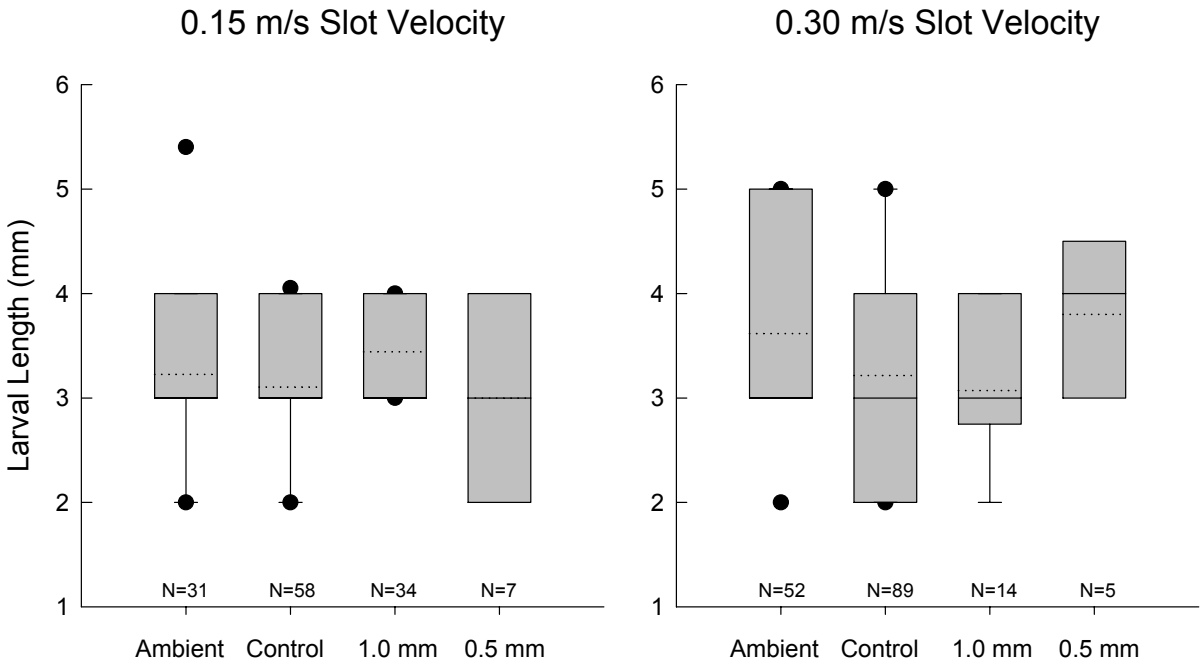

Figure 4-6
Box Plots Showing Median (solid line) and Mean (dotted line) Lengths of Freshwater Drum Larvae and 25-75th (box), 10-90th (whiskers), and 5-95th (dots) Percentiles

Shad

Shad (Clupeidae spp.) were by far the most abundant larvae, representing 93 percent of all larvae collected. Although larvae could only be identified to the family level, based on information provided by area researchers it is likely that most specimens were gizzard shad *(Dorosoma cepedianum)*. The abundance of alewife *(Alosa pseudoharengus)* documented in other areas of western Lake Erie suggest that they may have also been present in samples. Ambient density was a significant predictor of sample entrainment density ($p<0.05$). However, there was not a significant difference between test and control densities ($p>0.05$). The intake type/slot width was also insignificant ($p>0.05$), indicating that, even with a slot width of 0.5 mm there was no significant difference between test and control densities. The effect of slot velocity on sample density was insignificant ($p>0.05$), as was the effect of slot velocity on the difference between test and control densities ($p>0.05$). Because of the lack of significance among model terms, no post-hoc comparisons were made. The relationship between test and control densities is shown for each slot width and slot velocity on Figure 4-7.

While no overall differences were discernable based on the GLM, comparisons of test and control densities by length class suggest that differences may be highly dependent on larval size. Table 4-3 shows the mean densities of shad collected in ambient, control, and test samples by test condition for each length class. For trials with the 0.5 mm screen at both slot velocities, the densities of length classes greater than 3 mm in test samples were lower than in control samples, although these differences were only significant in two cells. Results for trials with the 1.0 mm screen also show higher densities in control samples, but only a significant difference in one cell. In general, an increasing trend in the difference between test and control samples can be seen as

length class increased. Although the consistently large differences seen for the larger length classes (>6 mm) were insignificant, this may be attributable to a small number of valid trials (typically less than six) as a result of patchy distribution of larger larvae. In general, there was not a noticeable difference in entrainment rates based on slot velocity, but this may be obscured by the small number of valid trials and the resulting variability. For nearly all length classes and test conditions, ambient densities were higher than both control and test densities.

To describe shad length distribution, and to further evaluate the effect of length on entrainment rates, box plots of shad lengths from each sample type are provided on Figure 4-8. For trials at a slot velocity of 0.15 m/s, larvae in both 0.5 mm and 1.0 mm screen samples were significantly smaller than both control and ambient samples ($p<0.008$). Larvae in control samples were also significantly smaller than in ambient samples ($p<0.008$). For trials at a slot velocity of 0.30 m/s, the only significant differences in larval length were between ambient samples and all other sample types ($p<0.008$).

The length of shad larvae was highly correlated with maximum head width ($r^2=0.96$; $p<0.05$; Figure 4-9). As suggested by the low slope of the regression line (0.084), shad larvae can be characterized as narrow-bodied. Based on this relationship, for a length of 4 mm (the median length observed in control samples), the expected head width would be 0.37 mm, which is considerably smaller than the width corresponding to the median length of all other species discussed herein.

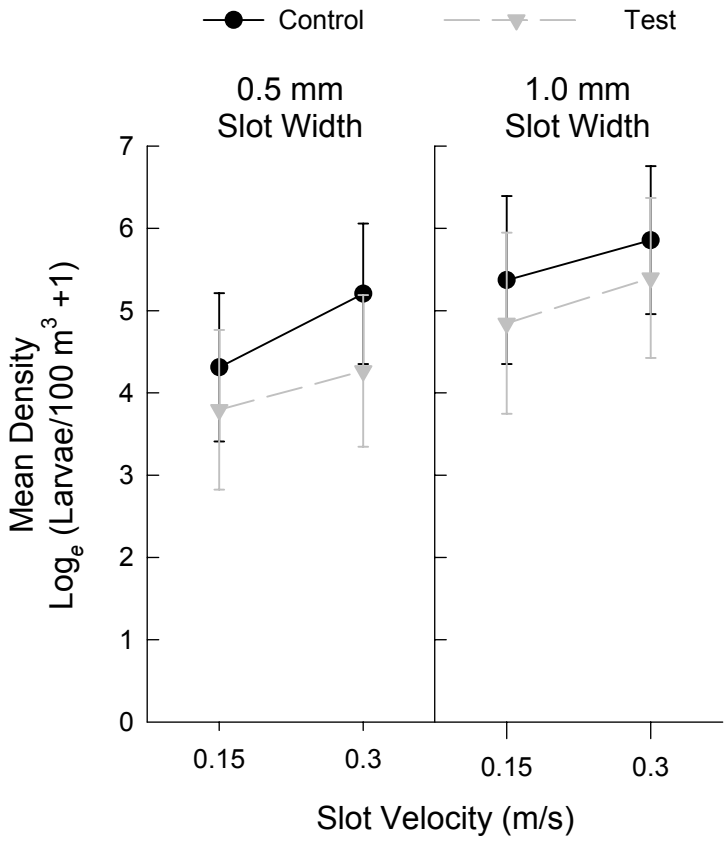

Figure 4-7
Mean Density (log transformed) of Shad Larvae Collected in Control and Test Samples with 95 Percent Confidence Intervals

Table 4-3
Mean density and standard deviation (SD) of shad larvae collected in ambient, control, and test samples during trials with 0.5 and 1.0 mm screens at slot velocities of 0.15 and 0.30 m/s. C-T is the percent difference between test and control densities.[a] Asterisks indicate a statistically significant difference between test and control densities ($p<0.05$).

Slot Width (mm)	Slot Velocity (m/s)	Larval Length (mm)	Mean Number Entrained per 100 m^3 (SD)			C-T Percent Difference (Valid Trials)
			Ambient	Control	Test	
0.5	0.15	≤3	46.4 (83.5)	51.6 (91.6)	59.6 (127.2)	-15.5 (9)
		4-6	662.5 (884.2)	88.2 (62.4)	57.1 (94.4)	35.2 (8)
		7-9	535.1 (1017.7)	8.4 (9.5)	0.1 (0.4)	98.2 (5)*
		≥10	28.4 (69.5)	0.0 (0.0)	0.0 (0.0)	N/A[b]
		All	1272.6 (1931.4)	148.2 (148.6)	116.9 (220.3)	21.1 (9)
	0.30	≤3	182.3 (357.5)	72.7 (98.8)	63.9 (90.6)	12.1 (10)
		4-6	822.3 (1591.5)	138.4 (122.2)	53.1 (50.4)	61.6 (10)*
		7-9	373.0 (790.9)	28.8 (51.6)	6.3 (9.9)	78.1 (6)
		≥10	10.6 (24.9)	4.5 (11.2)	0.0 (0.0)	100.0 (2)
		All	1388.3 (2365.2)	244.4 (182.4)	123.3 (125.3)	49.5 (10)*
1.0	0.15	≤3	83.4 (139.2)	97.2 (92.4)	54.4 (75.9)	44.0 (7)
		4-6	1902.5 (3036.2)	497.0 (1061.2)	455.9 (1119.4)	8.3 (7)
		7-9	237.1 (323.2)	20.7 (39.2)	0.8 (1.5)	96.1 (5)
		≥10	3.9 (9.3)	0.0 (0.0)	0.0 (0.0)	N/A[b]
		All	2226.9 (3304.0)	614.9 (1109.7)	511.1 (1097.7)	16.9 (7)
	0.30	≤3	158.7 (158.6)	283.9 (371.9)	382.4 (574.5)	-34.7 (9)
		4-6	937.9 (1367.7)	269.8 (230.9)	142.9 (168.9)	47.0 (9)*
		7-9	56.3 (56.4)	17.6 (26.1)	5.6 (11.2)	68.0 (4)
		≥10	4.2 (8.4)	0.0 (0.0)	0.0 (0.0)	N/A[b]
		All	1157.2 (1320.3)	571.3 (533.5)	530.9 (628.3)	7.1 (9)

[a] "C-T Percent Difference" is calculated as [(control density minus test density) divided by control density]. Thus, positive values indicate lower densities in test samples.
[b] Insufficient data for meaningful comparison

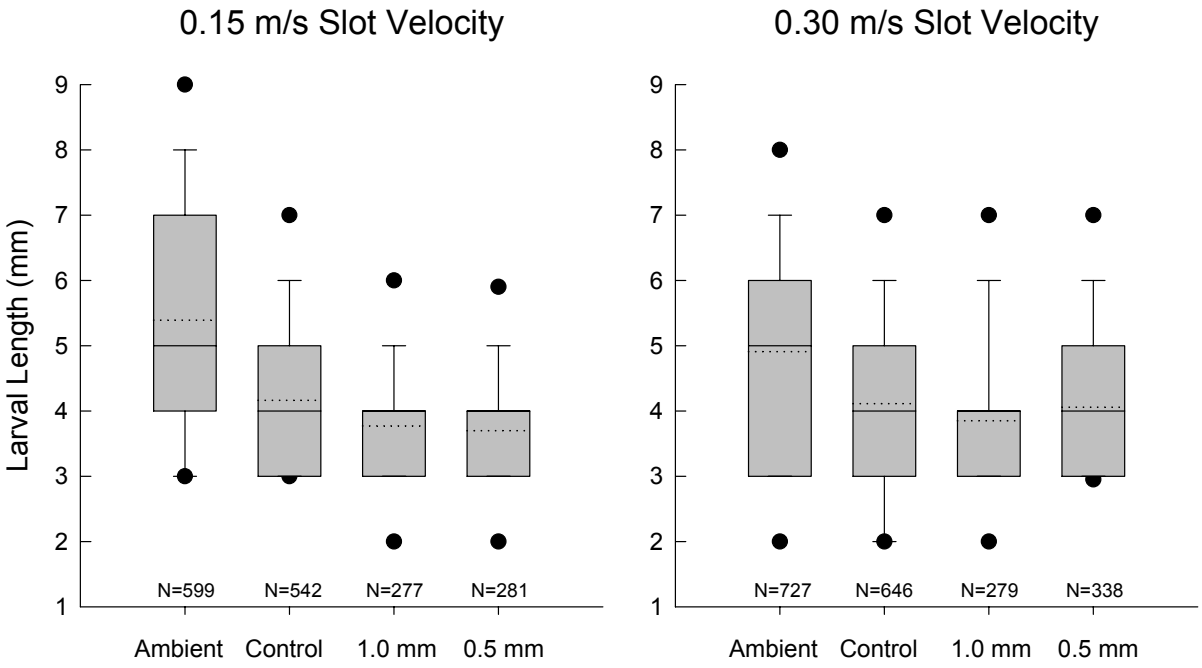

Figure 4-8
Box Plots Showing Median (solid line) and Mean (dotted line) Lengths of Shad Larvae and 25-75th (box), 10-90th (whiskers), and 5-95th (dots) Percentiles

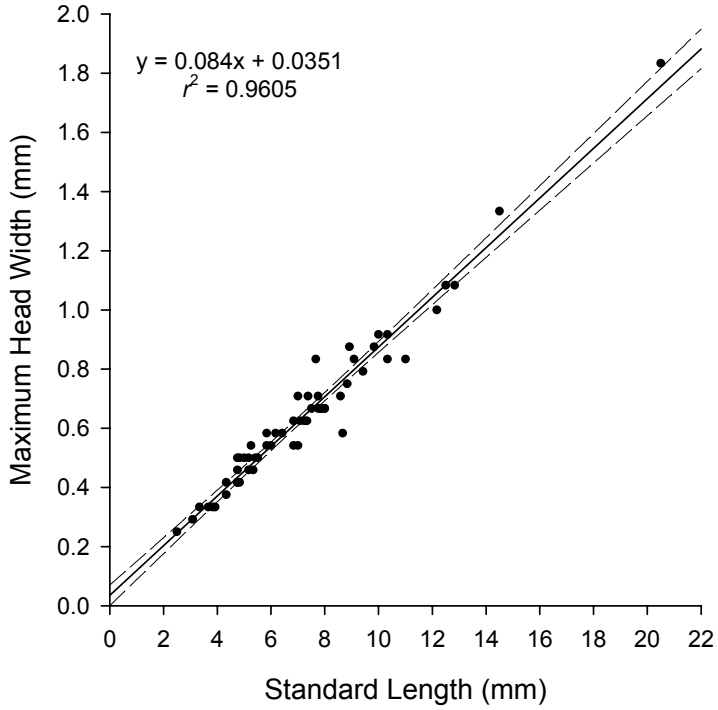

Figure 4-9
Maximum Head Width Plotted Against Standard Length of Shad Larvae with Regression Line and 95 Percent Confidence Bands

Temperate Basses

Temperate basses *(Morone spp.)* were the fourth most abundant larvae, but represented less than 1 percent of all larvae collected. Based on previous ichthyoplankton studies in the area, it is assumed that white perch and white bass were the *Morone* species collected, although it was not possible to differentiate between the two during sample analysis. As with all species except shad, there was insufficient data to perform analyses with the GLM, which limited analyses to pairwise comparisons between test and control densities using the Wilcoxon Matched Pairs Test. The percent difference between test and control densities was greater than 65 percent for all test conditions (Table 4-4). However, differences were based on six or fewer trials and were not significant. Mean ambient densities were considerably greater than both control and test densities for all test conditions.

Figure 4-10 shows box plots of temperate bass lengths for each sample type. There were no differences in larval lengths between sample types at either slot velocity. Again, however, the lack of length differences may be related to small sample sizes. Based on subsamples of temperate bass larvae, length and maximum head width were only moderately correlated (r^2=0.28; p<0.05; Figure 4-11).

Table 4-4
Mean density and standard deviation (SD) of temperate bass larvae collected in ambient, control, and test samples during trials with 0.5 and 1.0 mm screens at slot velocities of 0.15 and 0.30 m/s. C-T is the percent difference between test and control densities.[a] Asterisks indicate a statistically significant difference between test and control densities (p<0.05).

Slot Width (mm)	Slot Velocity (m/s)	Mean Number Entrained per 100 m^3 (SD)			C-T Percent Difference (Valid Trials)
		Ambient	Control	Test	
0.5	0.15	15.3 (25.6)	1.6 (2.3)	0.5 (1.1)	67.7 (6)
	0.30	15.2 (40.3)	0.7 (1.5)	0.2 (0.5)	65.7 (4)
1.0	0.15	38.2 (83.9)	0.4 (1.2)	0.0 (0.0)	N/A[b]
	0.30	21.6 (35.9)	0.4 (0.8)	0.0 (0.0)	100.0 (2)

[a] "C-T Percent Difference" is calculated as [(control density minus test density) divided by control density]. Thus, positive values indicate lower densities in test samples.
[b] Insufficient data for meaningful comparison

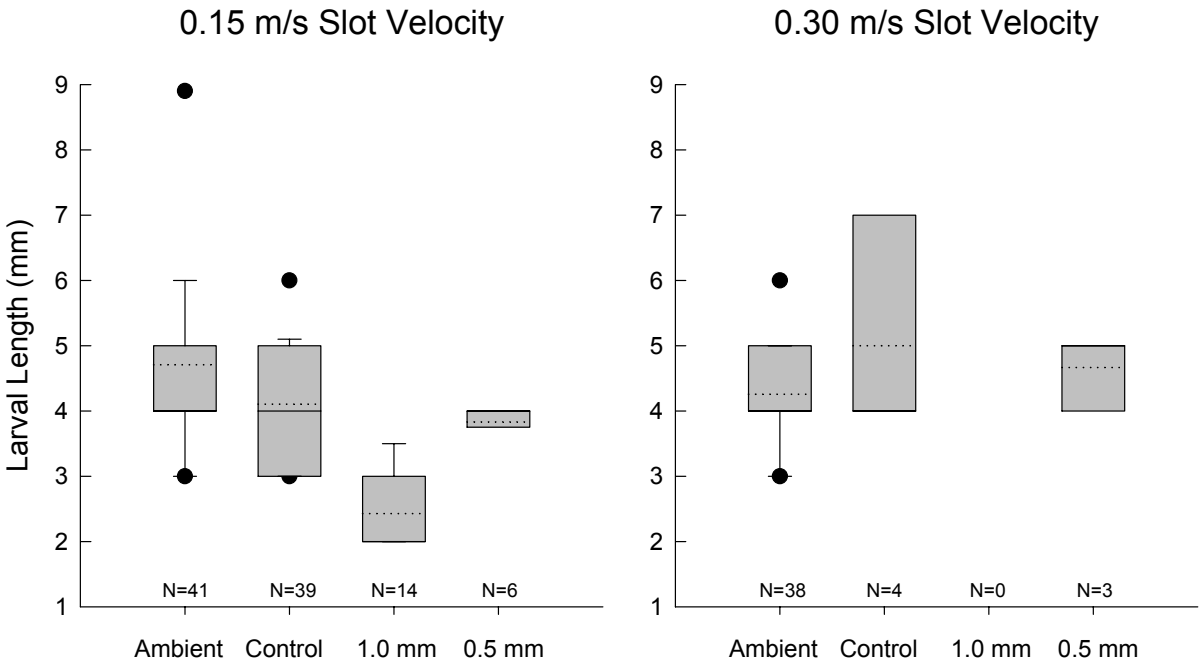

Figure 4-10
Box Plots Showing Median (solid line) and Mean (dotted line) Lengths of Temperate Bass Larvae and 25-75th (box), 10-90th (whiskers), and 5-95th (dots) Percentiles

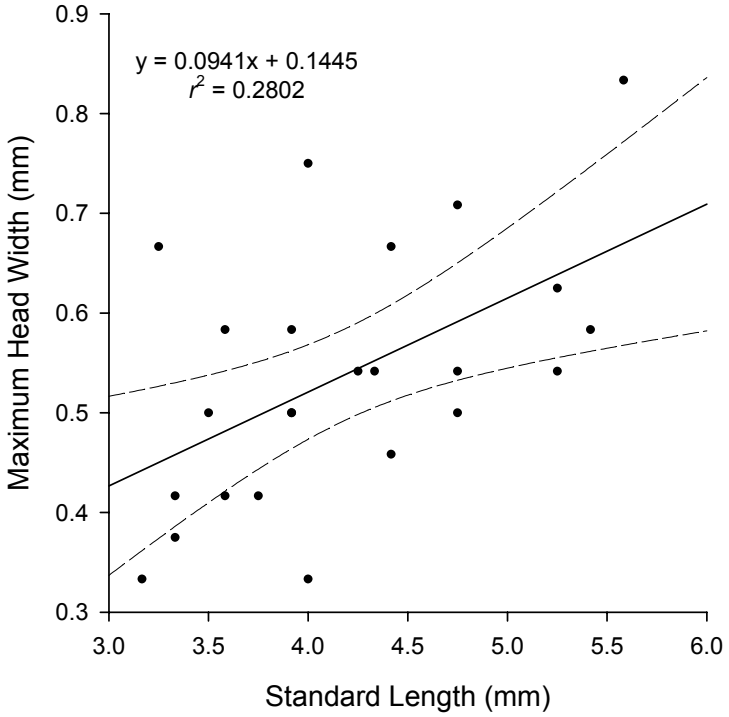

Figure 4-11
Maximum Head Width Plotted Against Standard Length of Temperate Bass Larvae with Regression Line and 95 Percent Confidence Bands

Eggs

Although the eggs collected from the Portage River were not taxonomically identified, the abundance of shad larvae and the proximity of spawning habitat suggest that most were likely shad eggs. Eggs were consistently present and abundant which resulted in a large number of valid trials and allowed for analysis using the GLM. There was not a significant overall difference between test and control samples ($p>0.05$). However, the intake type/slot width interaction was significant ($p<0.05$), indicating that the difference between test and control densities was dependent on slot width. Slot velocity did not have a significant effect on sample density ($p>0.05$), and did not have an effect on the difference between test and control densities ($p>0.05$). Ambient density was a significant predictor of sample density ($p<0.05$). Post-hoc comparisons revealed that the differences between test and control densities were significant for trials with the 0.5 mm screen at both slot velocities ($p<0.05$), and for the 1.0 mm screen trials at a slot velocity of 0.15 m/s ($p<0.05$). The differences between the mean test and control entrainment densities are shown for each slot width and slot velocity on Figure 4-12.

The mean densities of eggs collected in ambient, control, and test samples are shown by test condition in Table 4-5. The differences between control and test sample densities are also shown and are indicated where significant. Because data were analyzed using the GLM, significance reflects the results of post hoc comparisons of the log transformed densities. Differences between test and control densities were greater than 93 percent for all test conditions except for the slot width of 1.0 mm and slot velocity of 0.30 m/s. The small difference under these test conditions may be explained by extrusion of eggs through the larger slots at a higher velocity. The proximity of spawning habitat could also mean that eggs had been recently spawned and did not have ample time to water-harden, making them more susceptible to extrusion. For nearly all test conditions, mean densities were greater in ambient samples compared to test and control samples.

To characterize the size distribution of eggs and to compare egg sizes among sample types, the diameters of egg subsamples were measured in selected ambient and test samples (Figure 4-13). The overall mean egg diameter was 1.35 mm, which is 53 percent larger than the mean for eggs from the Sakonnet River, and may explain the greater entrainment reduction offered by the 1.0 mm screen in the Portage River. A comparison could not be made between the ambient and test samples selected for 0.5 mm slot width trials because only 3 eggs were present in the selected test samples. For trials with a slot width of 1.0 mm, ambient sample eggs (mean = 1.30 mm) were significantly smaller ($p<0.05$) than test sample eggs (mean = 1.42 mm), although the difference was only 0.12 mm.

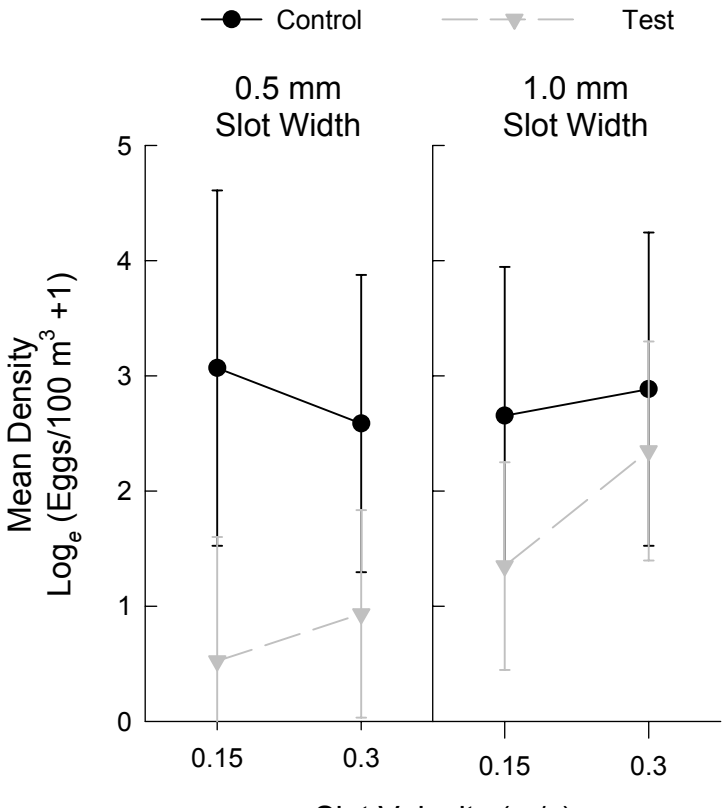

Figure 4-12
Mean Density (log transformed) of Eggs Collected in Control and Test Samples with 95 Percent Confidence Intervals

Table 4-5
Mean density and standard deviation (SD) of eggs collected in ambient, control, and test samples during trials with 0.5 and 1.0 mm screens at slot velocities of 0.15 and 0.30 m/s. C-T is the percent difference between test and control densities.[a] Asterisks indicate a statistically significant difference between test and control densities (p<0.05).

Slot Width (mm)	Slot Velocity (m/s)	Mean Number Entrained per 100 m^3 (SD)			C-T Percent Difference (Valid Trials)
		Ambient	Control	Test	
0.5	0.15	72.3 (130.2)	45.1 (81.5)	1.1 (3.1)	97.5 (7)*
	0.30	91.5 (199.8)	42.0 (81.0)	2.8 (4.3)	93.2 (10)*
1.0	0.15	74.0 (118.5)	102.9 (200.0)	4.5 (5.8)	95.7 (10)[b]
	0.30	737.7 (1806.4)	117.2 (224.1)	97.1 (195.5)	17.1 (9)

[a] "C-T Percent Difference" is calculated as [(control density minus test density) divided by control density]. Thus, positive values indicate lower densities in test samples.
[b] p=0.06

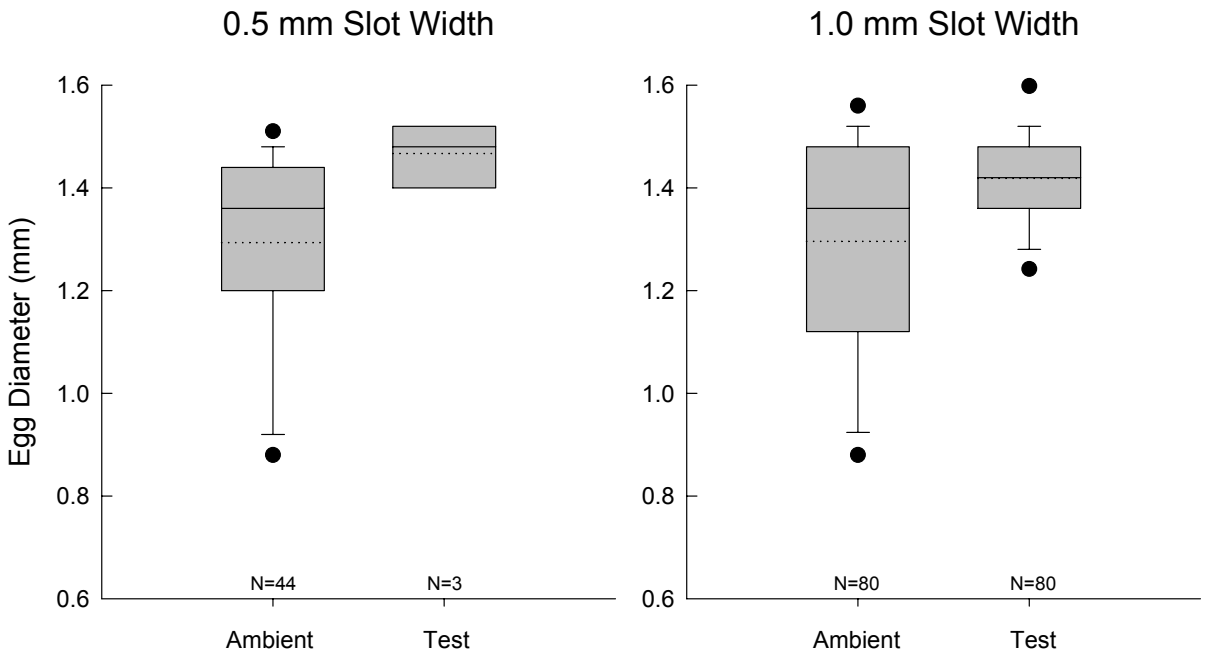

Figure 4-13
Box Plots Showing Median (solid line) and Mean (dotted line) Egg Diameter and 25-75th (box), 10-90th (whiskers), and 5-95th (dots) Percentiles for Eggs Collected from the Portage River

5
CONCLUSIONS AND DISCUSSION

The field evaluation of cylindrical wedgewire screens was successful in collecting a sufficient number of ichthyoplankton to provide meaningful entrainment reduction effectiveness estimates based on a variety of biological factors and design and operational parameters. In some cases, comparisons were hindered by low densities and the inherent variability in ichthyoplankton abundance, which reduced sample sizes and potentially obscured significant results. However, for some species, this study represents a relatively complete data set for predicting the field effectiveness of wedgewire screens under selected design and operational criteria.

The following are general conclusions based on the observed differences between ichthyoplankton densities entrained through an open (control) port and the two test screens:

- Entrainment densities were lower with a smaller slot width;
- In nearly all cases, slot velocities tested (0.15 and 0.3 m/s) did not have a significant effect on entrainment density;
- Larval entrainment densities in both control and test samples typically increased as ambient velocity increased, whereas egg entrainment densities were unaffected by ambient velocity;
- For both slot widths, entrainment density decreased with larval length; and,
- For species with larger head widths, the difference between control and test entrainment densities was greater.

The overall effectiveness of wedgewire screens varied depending on biological (species, morphology, size) and engineering (slot width) parameters. The following are detailed findings that will assist in predicting the effectiveness of wedgewire screens at future installations:

- For grubby larvae, the 0.5 mm screen significantly reduced entrainment by 92.5 percent or more for all length classes combined, and by 100 percent for larvae over 7 mm in length. For length classes 6 mm and smaller, entrainment reduction ranged from 77.8 to 92.5 percent. The 1.0 mm screen significantly reduced entrainment by 83.8 percent or more for larvae over 7 mm in length. The relatively large predicted median head width for grubby (0.98 mm) likely contributed to the high level of entrainment reduction observed for this species.
- Sand lance entrainment was only significantly reduced by the 0.5 mm screen, which provided mean reductions of 80.2 to 93.3 percent for all length classes combined. With a predicted median head width of 0.71 mm, most sand lance larvae were considerably narrower than a 1.0 mm slot, which likely precluded physical exclusion by the larger slot width.
- The 0.5 mm screen significantly reduced the mean entrainment of winter flounder by 43.8 to 56.2 percent for all length classes combined. For the 4-6 mm length class, the mean entrainment reduction was greater (61.2 to 76.9 percent). The 1.0 mm screen did not offer a

significant reduction in entrainment for any length class. The ineffectiveness of the 1.0 mm screen is likely a result of the relatively small head width (predicted median = 0.76 mm) of winter flounder exposed to the screen.

- The effectiveness of both screens for reducing entrainment of shad spp. was variable. For larvae 7 mm in length or greater, mean entrainment reduction ranged from 68.0 to 98.2 percent. The entrainment of larvae 4-6 mm in length was significantly reduced with the 0.5 mm screen (61.6 percent) and the 1.0 mm screen (47.0 percent) at a slot velocity of 0.30 m/s, but not at 0.15 m/s.
- The 0.5 mm slot width screen significantly reduced the entrainment of eggs. Mean entrainment reduction ranged from 92.5 to 99.9 percent for eggs with a mean diameter of 0.88 mm (Sakonnet River) and 93.2 to 97.5 percent for eggs with a mean diameter of 1.35 mm (Portage River). Although the 1.0 mm screen did not significantly reduce the entrainment of eggs at either site, at the slower slot velocity (0.15 m/s), the mean entrainment reduction was 95.7 percent ($p=0.06$) for eggs with a mean diameter of 1.35 mm (from the Portage River).
- When the difference between test and control entrainment densities was significant, the overall mean entrainment reduction was no more than 13 percent greater at a slot velocity of 0.15 m/s compared to a slot velocity of 0.30 m/s.

Cylindrical wedgewire screens act to reduce the entrainment of organisms via two distinct mechanisms (Weisberg et al. 1987). The first mechanism, physical exclusion, is predicated on the size of the organism being larger than the slot width to which it is exposed, such that the organism cannot physically pass through the opening. The second mechanism is hydrodynamic exclusion, which is facilitated by the rapid diffusion of the flow field immediately surrounding the wedgewire screen. The flow field uniformity and resulting reduction in velocities near the screen surface are promoted by the cylindrical design and can allow sufficiently motile larvae to avoid entrainment even if they are physically small enough to pass through the slot openings. Given these two mechanisms, the importance of an organism's life stage, morphology, overall size, and swimming abilities, which are all interrelated, become apparent. As an organism changes life stage, it also grows, becoming more motile as well as more likely to be physically excluded. Thus, larger larvae are not only more likely to be physically excluded, but they also will have greater swimming abilities to facilitate behavioral avoidance of an intake (EPRI 2003).

Although the open port in this study is considered the "control" for the purposes of comparison to the test screens, and the 9.5 mm mesh covering the control is unlikely to provide any physical exclusion, behavioral avoidance of the control intake may occur. Thus, comparing entrainment rates for the test and control intakes may underestimate the effectiveness of wedgewire screens relative to ambient densities. In the present study, higher densities were typically found in ambient samples when compared to test and control samples. Because ambient samples were collected by actively towing a 1-m plankton net, the probability of avoidance is reduced. Weisberg et al. (1987) and Zeitoun et al. (1981a) found that densities in ambient samples were greater than in samples collected in entrainment samples and suggested that the difference may be due in part to avoidance of the experimental intakes. However, differences in collection techniques for ambient and entrainment samples may account for some of the density differences. Relative to ambient collections, the method of collecting entrainment samples through the experimental intakes may have resulted in more physical damage to organisms,

rendering some larvae unidentifiable and reducing density estimates. Because the degree to which this occurred was not quantifiable, the differences between ambient and test sample densities were not emphasized in this study, and rather the differences between test and control densities were focused on to evaluate screen effectiveness.

The variable that had the greatest effect on the difference between test and control densities was slot width. Results of the statistical analysis showed that slot width had a significant effect on the difference between test and control densities for every species except shad. For grubby, the 0.5 mm screen provided an overall entrainment reduction of more than 92 percent. For larvae greater than 6 mm in length, the reduction increased to 100 percent. The reduction for sand lance was more than 80 percent overall, and greater than 95 percent for larvae over 10 mm in length. For winter flounder, which were considerably smaller than other species, the overall reduction was over 43 percent. In contrast, the only species for which the 1.0 mm screen offered a significant overall reduction was grubby, though significant size-specific reductions were found for other species. At both sites, the reduction in egg density with the 0.5 mm screen was between 93 and 100 percent. Results with the 1.0 mm screen were more variable, ranging from 8 to 96 percent. However, the eggs at both test sites were relatively small, and screens with 1 mm slot widths have been shown to be effective at reducing entrainment of eggs that are 2.3 mm in diameter or greater (Hanson 1979).

The greater effectiveness of the smaller slot width is consistent with results of the EPRI laboratory study (EPRI 2003), which attributed the difference to a lack of physical exclusion as well as behavioral avoidance at greater slot widths (1.0 and 2.0 mm). Browne et al. (1981) found that a slot width of 0.5 mm excluded most eggs and larvae, whereas entrainment rates with a slot width of 1.0 mm were higher for larvae less than 10 mm in length. However, studies have also shown that, for larvae greater than 10 mm in length, larger slot widths (1 mm or greater) can effectively reduce entrainment (EPRI 2003; Hanson et al. 1978; Hanson 1981; Heuer and Tomljanovich 1979; Otto et al. 1981). Our results also demonstrate that, while smaller larvae were not effectively excluded with the 1.0 mm screen, entrainment reduction for larger larvae (7 mm and greater) was often greater than 68 percent (e.g., shad and grubby).

Although length has a demonstrated effect on exclusion efficiency and is important with respect to both physical exclusion and swimming ability, larval head width is likely to have a more direct relationship with physical exclusion because it is the limiting dimension in determining a larvae's susceptibility to entrainment through a given slot size. Based on this assumption, Schneeberger and Jude (1981) performed a regression analysis of body depth and length for several species to estimate the percentage of entrained larvae of known lengths that would be excluded by a 0.5 mm screen compared to an existing 9.5 mm screen. They predicted that the resulting physical exclusion would yield an entrainment reduction of 35-100 percent, depending on species. Based on a known length-width relationship, Weisberg et al. (1987) were able to identify the mechanism of physical exclusion by noting the absence of larvae greater than 10 mm in length, which corresponded to a width of greater than 1 mm in samples collected through a 1 mm screen. They identified hydrodynamic exclusion based on low entrainment rates of 5-mm long fish exposed to a 3-mm mesh screen, even though they were narrow enough to become entrained.

Using the length-width regression equations provided in the results section for each species, the expected length at which larvae would have a certain head width can be estimated. For the most abundant species, Table 5-1 shows the predicted lengths that correspond to head widths of 0.5 and 1.0 mm (i.e., head widths that are equal to the two screen slot widths evaluated). Revisiting the results for each of these species shows that, for length classes smaller than the calculated lengths below, there is typically not a significant reduction in entrainment. Thus, there is not conclusive evidence for hydrodynamic exclusion in this case. In contrast, examining the length classes greater than the calculated values below shows more evidence for physical exclusion.

Table 5-1
Predicted larval lengths corresponding to head widths of 0.5 and 1.0 mm for abundant species collected at the two study sites.

Species	Length at 0.5 mm Head Width	Length at 1.0 mm Head Width
Grubby	3.4	5.1
Sand Lance	5.4	11.7
Winter Flounder	2.5	5.4
Shad	5.5	11.5

The effect of physical exclusion is also noticeable when considering the species-specific differences in sample densities. Based on the length-width relationships, grubby can be characterized as the widest larvae for a given length. Consequently, the entrainment reduction provided by wedgewire screens is considerably greater for grubby than any other species. In contrast, sand lance were much narrower despite having a greater length. Their morphology is likely a contributing factor in the relatively low reduction in entrainment offered by the screens.

In the EPRI laboratory study (EPRI 2003), slot velocity was found to have a significant effect on entrainment rates for several species. Entrainment rates typically increased as slot velocity increased. However, results showed that slot velocities of 0.30 m/s may be biologically effective depending on fish size, slot width, and ambient velocity. The results of the present study did not indicate that slot velocity affected ichthyoplankton densities for either control or test samples under most conditions. While an effect of slot velocity may have been obscured by the high variability in sample densities, the effect of slot velocity appears to be minimal compared to the effect of slot width. In addition, the EPRI laboratory study found that, given sufficient ambient velocities, the effect of slot velocity is reduced. In the case of testing in the Sakonnet River, the relatively high ambient velocities under which much of the testing was performed may have effectively countered any potential influence of slot velocity on the difference between test and control entrainment densities.

Several studies have demonstrated that ambient velocity is an important factor in reducing entrainment of ichthyoplankton exposed to wedgewire screens (EPRI 2003; Hanson et al. 1978, Heuer and Tomljanovich 1978). Higher ambient velocities produce a sweeping flow that can carry organisms along the face of a screen and remove organisms if they become impinged. Although this study indicated that ambient velocity did have a significant effect on entrainment density, these results seemingly contradict previous observations because densities usually

increased as ambient velocity increased. Typically, this trend was observed in both test and control samples. The most plausible explanation is that, at higher ambient velocities, a greater number of larvae come in contact with the intakes. Thus, higher velocities, in effect, increase the ambient density of organisms from which samples are taken. However, given that the slot velocity and intake flow rate remain the same regardless of ambient velocity, one would assume that the number of organisms entrained should not change. The ultimate cause of greater entrainment may be a function of behavioral avoidance. The EPRI laboratory tests were performed with a maximum ambient velocity of 0.3 m/s, whereas ambient velocities in the Sakonnet River were as high as 1.1 m/s. At a lower ambient velocity range, larvae approaching the screen may still be able to orient rheotactically and use the ambient current to avoid entrainment. However, at velocities approaching 1 m/s, larvae essentially become passive particles. In fact, ambient velocity did not have an effect on egg entrainment. Unlike larvae, an egg will always behave as a passive particle, regardless of ambient velocity and its probability of entrainment will not be affected. These results suggest that ambient velocity may only improve the effectiveness of a screen to a certain point, beyond which it interferes with avoidance behavior. Unfortunately, the variability in the data limits the analysis to simply identifying a trend, and prevents us from identifying a point at which such a transition might take place.

The data collected during the field evaluation of wedgewire screens demonstrate their effectiveness for reducing ichthyoplankton entrainment at CWIS under certain conditions and highlight the importance of design and operational parameters as well as biological factors. A slot width of 0.5 mm was found to reduce entrainment by 60 percent or more for most species, size classes, and life stages regardless of slot velocity. The effectiveness of the 1.0 mm screen was more dependent on other factors and may not be as broadly applicable. However, given certain conditions, such as species type, typical larval sizes, or hydraulic conditions, larger slot widths may prove to be effective. In a study evaluating wedgewire screens at an offshore location and an intake channel, Zeitoun et al. (1981b) found that intake location was an important factor in determining design criteria, as effectiveness varied based on site-specific biological characteristics and water currents.

The results and discussion herein have been limited to the effectiveness of wedgewire screens for reducing entrainment. Impingement reduction is also a significant concern in identifying appropriate and effective technologies. The evaluation of impingement rates was precluded by the difficulty of quantifying impingement in a field setting. However, it is unlikely that juvenile or adult fish will become impinged on wedgewire screens at such low slot velocities. In addition, previous laboratory studies with selected species have shown that, with optimal design and operational conditions, impingement of eggs and larvae is low as well. Although biofouling and debris loading on full-scale wedgewire screen installations may result in high-velocity “hot spots” and cause localized increases in impingement, proper maintenance and cleaning woulod alleviate this potential problem.

The results of this study indicate that an increase in slot velocity from 0.15 to 0.30 m/s did not significantly affect entrainment rates. Further laboratory research could be conducted to determine if slot velocity can also be increased without significantly increasing the impingement rates of eggs and larvae. If slot velocity can be increased without significantly increasing entrainment or impingement rates, the number of screens required at an installation would be reduced, offering a substantial cost savings.

With the exception of shad, the data collected for species from the Portage River was limited and prevented comprehensive evaluations of most test parameters. Future studies could also build upon the dataset for these species. Additional research opportunities include performing a similar field evaluation in other water body types (e.g., water bodies in the southern U.S. or midwestern rivers) or further investigating the correlation between head width, body length, and entrainment rates in the laboratory to develop a database of potential surrogate species for predicting the effectiveness of wedgewire screens. Continued research will provide more specific criteria and broaden the general applicability of wedgewire screens to a wider range of applications.

The results of this study indicate that 0.5 and 1.0 mm wedgewire screens have the capability to physically exclude eggs and larvae of the species evaluated (and species with similar critical dimensions). In most cases, the level of exclusion is high enough to meet EPA's 316(b) entrainment reduction performance standard under many of the conditions studied.

6
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A
EARLY LIFE STAGE LENGTHS

Table A-1
Early Life Stage Lengths

Species	Life Stage	Standard Length (mm)	Reference
Grubby[a]	Yolk-Sac	6.8	Fritzsche 1978
	Post Yolk-Sac	8.5 to 14	
	Juvenile	14.5 to 15.1	
Sand Lance	Yolk-Sac	3 to 7	Fritzsche 1978
	Post Yolk-Sac	7 to 33.5	
	Juvenile	42.6	
Winter Flounder	Yolk-Sac	2.3 to 3.5	Martin and Drewry 1978
	Post Yolk-Sac	4.2	
	Juvenile	6 to 9	
Carp[b]	Yolk-Sac	3 to 8	Heufelder and Fuiman 1982
	Post Yolk-Sac	8 to 21	
	Juvenile	21 to 31	
Freshwater Drum	Yolk-Sac	3.2 to 4.2	Fuiman 1982a
	Post Yolk-Sac	4 to 17	
	Juvenile	15 to 22	
Shad[c]	Yolk-Sac	3 to 7	Tin 1982
	Post Yolk-Sac	6 to 20	
	Juvenile	20 to 50	
Temperate Basses[d]	Yolk-Sac	1.7 to 5	Fuiman 1982b
	Post Yolk-Sac	8 to 13	
	Juvenile	19	

[a] Data for longhorn sculpin *(Myoxocephalus octodecemspinusus)* used as congeneric surrogate for grubby
[b] Data for common carp *(Cyprinus carpio)*
[c] Data for gizzard shad *(Dorosoma cepedianum)*
[d] Data for white bass *(Morone americana)*

B
ENTRAINMENT DATA – ESTUARINE TESTING

The following tables summarize entrainment data collected at the Sakonnet River site (Appendix B) and the Portage River site (Appendix C). Data are sorted by species or life stage. Slot width and slot velocity refer to test samples only. Mean ambient velocity reflects the average water velocity as it approached the barge over the course of a trial. Ambient, control, and test densities are ichthyoplankton densities per 100 m^3. Note that, for estuarine testing, a single ambient sample was taken as a representative sample for three consecutive trials. Thus, in most instances identical ambient density values are actually from the same sample. For the sake of brevity, trials in which ichthyoplankton were not collected in any of the samples (ambient, control, or test) have been omitted.

Table B-1
Entrainment data collected at the Sakonnet River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
American Eel	1.00	0.15	0.33	R10	115	1.08	0.00	0.00
American Eel	1.00	0.15	0.06	R10	116	1.08	0.00	0.00
American Eel	1.00	0.30	0.44	R10	114	1.08	0.00	0.00
Atlantic herring	0.50	0.15	0.79	R03	23	0.00	3.45	0.00
Atlantic herring	0.50	0.30	0.71	R08	84	0.00	2.32	0.00
Atlantic herring	1.00	0.15	0.18	R07	76	1.42	0.00	0.00
Atlantic herring	1.00	0.15	0.96	R07	77	1.42	0.00	0.00
Atlantic herring	1.00	0.15	0.62	R07	78	1.42	0.00	0.00
Cusk Eel	0.50	0.30	0.23	R04	34	0.90	0.00	0.00
Cusk Eel	0.50	0.30	0.95	R04	35	0.90	0.00	0.00
Cusk Eel	0.50	0.30	0.95	R04	36	0.90	0.00	0.00
Eggs	0.50	0.15	0.69	R01	1	4.86	3.97	0.00
Eggs	0.50	0.15	0.93	R01	2	4.86	0.00	0.00
Eggs	0.50	0.15	0.76	R01	3	4.86	0.00	0.00
Eggs	0.50	0.15	0.59	R02	13	21.68	11.73	0.00
Eggs	0.50	0.15	0.42	R02	14	21.68	6.66	0.00
Eggs	0.50	0.15	0.21	R02	15	21.68	5.58	0.00
Eggs	0.50	0.15	0.14	R03	22	1.77	7.25	0.00
Eggs	0.50	0.15	0.79	R03	23	1.77	24.16	0.00
Eggs	0.50	0.15	0.73	R03	24	1.77	35.71	0.00
Eggs	0.50	0.15	0.76	R04	37	16.59	20.72	0.00

Table B-1 (continued)
Entrainment data collected at the Sakonnet River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Eggs	0.50	0.15	0.62	R04	38	16.59	33.83	0.00
Eggs	0.50	0.15	0.23	R04	39	16.59	38.95	0.00
Eggs	0.50	0.15	0.16	R05	46	18.80	7.01	0.00
Eggs	0.50	0.15	0.53	R05	47	18.80	13.04	0.00
Eggs	0.50	0.15	0.64	R05	48	18.80	25.59	0.00
Eggs	0.50	0.15	0.62	R06	61	4.41	12.15	0.00
Eggs	0.50	0.15	0.14	R06	62	4.41	5.47	0.00
Eggs	0.50	0.15	0.04	R06	63	4.41	15.15	0.00
Eggs	0.50	0.15	0.15	R07	70	44.19	30.15	0.00
Eggs	0.50	0.15	0.82	R07	71	44.19	19.05	0.00
Eggs	0.50	0.15	0.74	R07	72	44.19	21.45	0.00
Eggs	0.50	0.15	0.47	R08	85	13.84	18.56	0.00
Eggs	0.50	0.15	0.21	R08	86	13.84	11.82	0.00
Eggs	0.50	0.15	0.03	R08	87	13.84	0.00	0.00
Eggs	0.50	0.15	0.17	R09	88	6.07	12.57	32.53
Eggs	0.50	0.15	0.70	R09	89	6.07	11.40	0.00
Eggs	0.50	0.15	0.49	R09	90	6.07	21.10	0.00
Eggs	0.50	0.15	0.21	R10	96	9.61	11.34	0.00
Eggs	0.50	0.15	0.47	R10	97	9.61	11.92	0.00
Eggs	0.50	0.15	0.43	R10	98	9.61	0.00	0.00
Eggs	0.50	0.30	0.47	R01	4	169.24	3.80	0.00
Eggs	0.50	0.30	0.02	R01	5	169.24	5.53	0.00
Eggs	0.50	0.30	0.05	R01	121	120.09	122.06	0.00
Eggs	0.50	0.30	0.14	R02	10	0.00	12.61	0.00
Eggs	0.50	0.30	0.73	R02	11	0.00	9.11	0.00
Eggs	0.50	0.30	0.99	R02	12	0.00	10.80	0.00
Eggs	0.50	0.30	0.35	R03	25	86.56	23.55	0.00
Eggs	0.50	0.30	0.36	R03	26	86.56	32.41	0.00
Eggs	0.50	0.30	0.15	R03	27	86.56	33.33	0.00
Eggs	0.50	0.30	0.23	R04	34	12.59	16.69	0.00
Eggs	0.50	0.30	0.95	R04	35	12.59	12.83	0.00
Eggs	0.50	0.30	0.95	R04	36	12.59	12.25	0.00
Eggs	0.50	0.30	0.60	R05	49	34.86	18.97	0.00
Eggs	0.50	0.30	0.29	R05	50	34.86	27.50	0.00
Eggs	0.50	0.30	0.07	R05	51	34.86	16.84	0.00
Eggs	0.50	0.30	0.24	R06	58	8.10	20.01	0.00
Eggs	0.50	0.30	0.87	R06	59	8.10	16.74	0.00
Eggs	0.50	0.30	0.96	R06	60	8.10	22.75	0.00
Eggs	0.50	0.30	0.46	R07	73	6.34	22.92	0.00

Table B-1 (continued)
Entrainment data collected at the Sakonnet River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Eggs	0.50	0.30	0.20	R07	74	6.34	22.91	0.00
Eggs	0.50	0.30	0.02	R07	75	6.34	14.12	0.00
Eggs	0.50	0.30	0.05	R08	82	0.00	0.00	0.62
Eggs	0.50	0.30	0.25	R08	83	0.00	8.19	0.00
Eggs	0.50	0.30	0.71	R08	84	0.00	3.87	0.00
Eggs	0.50	0.30	0.44	R09	91	120.43	30.41	0.00
Eggs	0.50	0.30	0.29	R09	92	120.43	31.94	0.00
Eggs	0.50	0.30	0.07	R09	122		93.56	0.00
Eggs	0.50	0.30	0.05	R10	93		15.44	0.00
Eggs	0.50	0.30	0.52	R10	94		12.17	0.00
Eggs	0.50	0.30	0.81	R10	95		9.18	0.00
Eggs	1.00	0.15	0.85	R01	6	0.00	12.16	12.72
Eggs	1.00	0.15	0.54	R01	7	0.00	0.00	20.92
Eggs	1.00	0.15	0.30	R01	8	0.00	0.00	1.83
Eggs	1.00	0.15	0.30	R01	117	108.17	132.89	83.73
Eggs	1.00	0.15	0.77	R01	118	108.17	115.13	92.26
Eggs	1.00	0.15	0.41	R02	19	119.04	0.00	3.40
Eggs	1.00	0.15	0.23	R02	20	119.04	12.91	3.75
Eggs	1.00	0.15	0.29	R02	21	119.04	33.23	21.00
Eggs	1.00	0.15	0.29	R03	28	25.06	6.13	10.81
Eggs	1.00	0.15	1.02	R03	29	25.06	31.51	17.76
Eggs	1.00	0.15	0.95	R03	30	25.06	40.27	21.47
Eggs	1.00	0.15	0.76	R04	43	30.90	29.58	18.15
Eggs	1.00	0.15	0.54	R04	44	30.90	21.84	41.35
Eggs	1.00	0.15	0.13	R04	45	30.90	22.69	30.15
Eggs	1.00	0.15	0.16	R05	52	80.42	14.88	9.36
Eggs	1.00	0.15	0.63	R05	53	80.42	35.56	20.50
Eggs	1.00	0.15	0.94	R05	54	80.42	21.11	26.86
Eggs	1.00	0.15	0.70	R06	67	49.86	46.37	39.07
Eggs	1.00	0.15	0.21	R06	68	49.86	27.84	48.09
Eggs	1.00	0.15	0.13	R06	69	49.86	38.97	27.07
Eggs	1.00	0.15	0.18	R07	76	7.09	12.48	10.65
Eggs	1.00	0.15	0.96	R07	77	7.09	9.01	4.58
Eggs	1.00	0.15	0.62	R07	78	7.09	8.98	7.29
Eggs	1.00	0.15	0.59	R08	102	105.02	56.02	28.62
Eggs	1.00	0.15	0.48	R08	103	105.02	49.60	32.14
Eggs	1.00	0.15	0.16	R08	104	105.02	41.84	41.63
Eggs	1.00	0.15	0.20	R09	105	58.00	83.28	38.31
Eggs	1.00	0.15	0.48	R09	106	58.00	65.71	48.65

Table B-1 (continued)
Entrainment data collected at the Sakonnet River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Eggs	1.00	0.15	0.51	R09	107	58.00	79.85	42.71
Eggs	1.00	0.15	0.71	R09	108	58.35	33.38	37.30
Eggs	1.00	0.15	0.33	R10	115	119.29	137.17	63.06
Eggs	1.00	0.15	0.06	R10	116	119.29	122.41	75.54
Eggs	1.00	0.30	0.15	R01	9	0.00	0.00	0.99
Eggs	1.00	0.30	0.50	R01	119	120.09	118.73	78.10
Eggs	1.00	0.30	0.47	R01	120	120.09	130.60	102.75
Eggs	1.00	0.30	0.09	R02	16	5.80	9.51	4.17
Eggs	1.00	0.30	1.02	R02	17	5.80	7.19	4.74
Eggs	1.00	0.30	0.69	R02	18	5.80	2.06	1.09
Eggs	1.00	0.30	0.63	R03	31	23.73	34.70	28.24
Eggs	1.00	0.30	0.62	R03	32	23.73	14.41	26.36
Eggs	1.00	0.30	0.47	R03	33	23.73	25.99	20.98
Eggs	1.00	0.30	0.16	R04	40	3.23	19.21	7.30
Eggs	1.00	0.30	0.67	R04	41	3.23	27.88	33.65
Eggs	1.00	0.30	0.84	R04	42	3.23	45.46	25.53
Eggs	1.00	0.30	0.97	R05	55	8.32	15.77	17.80
Eggs	1.00	0.30	0.50	R05	56	8.32	6.02	10.68
Eggs	1.00	0.30	0.06	R05	57	8.32	14.10	18.16
Eggs	1.00	0.30	0.04	R06	64	24.40	20.86	15.71
Eggs	1.00	0.30	0.30	R06	65	24.40	32.64	43.80
Eggs	1.00	0.30	0.88	R06	66	24.40	40.37	119.97
Eggs	1.00	0.30	0.58	R07	79	0.00	3.34	6.27
Eggs	1.00	0.30	0.35	R07	80	0.00	0.81	5.86
Eggs	1.00	0.30	0.04	R07	81	0.00	19.65	9.69
Eggs	1.00	0.30	0.09	R08	99	46.34	82.46	69.91
Eggs	1.00	0.30	0.44	R08	100	46.34	70.34	53.49
Eggs	1.00	0.30	0.67	R08	101	46.34	0.00	0.00
Eggs	1.00	0.30	0.66	R09	109	58.35	46.46	47.75
Eggs	1.00	0.30	0.12	R09	110	58.35	42.39	60.08
Eggs	1.00	0.30	0.38	R10	111	111.07	122.95	98.43
Eggs	1.00	0.30	0.59	R10	112	111.07	119.31	104.37
Eggs	1.00	0.30	0.53	R10	113	111.07	105.15	86.87
Eggs	1.00	0.30	0.44	R10	114	119.29	107.57	84.03
Fourbeard Rockling	1.00	0.30	0.09	R08	99	1.32	0.00	0.00
Fourbeard Rockling	1.00	0.30	0.44	R08	100	1.32	0.00	0.00
Fourbeard Rockling	1.00	0.30	0.67	R08	101	1.32	0.00	0.00
Grubby	0.50	0.15	0.69	R01	1	75.84	27.76	0.00
Grubby	0.50	0.15	0.93	R01	2	75.84	62.43	0.00

Table B-1 (continued)
Entrainment data collected at the Sakonnet River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Grubby	0.50	0.15	0.76	R01	3	75.84	19.90	1.38
Grubby	0.50	0.15	0.59	R02	13	18.35	9.39	2.12
Grubby	0.50	0.15	0.42	R02	14	18.35	17.77	5.39
Grubby	0.50	0.15	0.21	R02	15	18.35	5.58	0.00
Grubby	0.50	0.15	0.14	R03	22	53.02	7.25	0.00
Grubby	0.50	0.15	0.79	R03	23	53.02	77.65	1.47
Grubby	0.50	0.15	0.73	R03	24	53.02	80.74	0.00
Grubby	0.50	0.15	0.76	R04	37	5.28	6.91	0.00
Grubby	0.50	0.15	0.62	R04	38	5.28	8.46	0.00
Grubby	0.50	0.15	0.23	R04	39	5.28	0.00	0.00
Grubby	0.50	0.15	0.16	R05	46	25.07	3.51	0.00
Grubby	0.50	0.15	0.53	R05	47	25.07	18.84	0.00
Grubby	0.50	0.15	0.64	R05	48	25.07	20.79	0.00
Grubby	0.50	0.15	0.62	R06	61	0.00	5.06	1.45
Grubby	0.50	0.15	0.04	R06	63	0.00	3.03	0.00
Grubby	0.50	0.15	0.15	R07	70	6.63	0.00	1.22
Grubby	0.50	0.15	0.82	R07	71	6.63	1.36	0.00
Grubby	0.50	0.15	0.74	R07	72	6.63	2.68	0.00
Grubby	0.50	0.15	0.47	R08	85	0.00	7.73	0.00
Grubby	0.50	0.15	0.21	R08	86	0.00	6.76	0.00
Grubby	0.50	0.15	0.17	R09	88	1.21	0.00	0.00
Grubby	0.50	0.15	0.70	R09	89	1.21	1.90	0.00
Grubby	0.50	0.15	0.49	R09	90	1.21	3.52	0.00
Grubby	0.50	0.15	0.21	R10	96	9.61	0.00	0.00
Grubby	0.50	0.15	0.47	R10	97	9.61	0.00	0.00
Grubby	0.50	0.15	0.43	R10	98	9.61	0.00	0.00
Grubby	0.50	0.30	0.47	R01	4	16.92	24.30	2.22
Grubby	0.50	0.30	0.02	R01	5	16.92	3.95	0.00
Grubby	0.50	0.30	0.05	R01	121	0.87	0.82	0.00
Grubby	0.50	0.30	0.14	R02	10	33.32	26.61	2.47
Grubby	0.50	0.30	0.73	R02	11	33.32	63.79	0.83
Grubby	0.50	0.30	0.99	R02	12	33.32	68.42	2.20
Grubby	0.50	0.30	0.35	R03	25	0.00	5.49	1.47
Grubby	0.50	0.30	0.36	R03	26	0.00	4.86	0.00
Grubby	0.50	0.30	0.15	R03	27	0.00	3.97	0.00
Grubby	0.50	0.30	0.23	R04	34	12.59	6.68	3.83
Grubby	0.50	0.30	0.95	R04	35	12.59	27.49	0.00
Grubby	0.50	0.30	0.95	R04	36	12.59	16.34	0.00
Grubby	0.50	0.30	0.60	R05	49	5.23	9.99	0.00

Table B-1 (continued)
Entrainment data collected at the Sakonnet River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Grubby	0.50	0.30	0.29	R05	50	5.23	0.00	2.69
Grubby	0.50	0.30	0.07	R05	51	5.23	3.37	0.00
Grubby	0.50	0.30	0.24	R06	58	24.29	0.00	2.39
Grubby	0.50	0.30	0.87	R06	59	24.29	11.16	0.00
Grubby	0.50	0.30	0.96	R06	60	24.29	7.58	0.00
Grubby	0.50	0.30	0.46	R07	73	6.34	1.76	0.00
Grubby	0.50	0.30	0.20	R07	74	6.34	4.58	0.00
Grubby	0.50	0.30	0.02	R07	75	6.34	0.00	1.55
Grubby	0.50	0.30	0.05	R08	82	20.81	0.70	0.62
Grubby	0.50	0.30	0.25	R08	83	20.81	5.21	0.71
Grubby	0.50	0.30	0.71	R08	84	20.81	3.10	0.00
Grubby	0.50	0.30	0.52	R10	94		0.87	0.00
Grubby	0.50	0.30	0.81	R10	95		0.83	0.00
Grubby	1.00	0.15	0.85	R01	6	8.86	111.90	25.43
Grubby	1.00	0.15	0.54	R01	7	8.86	66.47	53.79
Grubby	1.00	0.15	0.30	R01	8	8.86	7.49	36.62
Grubby	1.00	0.15	0.30	R01	117	1.98	0.00	0.00
Grubby	1.00	0.15	0.77	R01	118	1.98	1.54	1.59
Grubby	1.00	0.15	0.41	R02	19	0.00	8.96	0.00
Grubby	1.00	0.15	0.23	R02	20	0.00	0.00	1.87
Grubby	1.00	0.15	0.29	R02	21	0.00	1.75	0.00
Grubby	1.00	0.15	0.29	R03	28	30.08	3.06	0.00
Grubby	1.00	0.15	1.02	R03	29	30.08	26.66	12.69
Grubby	1.00	0.15	0.95	R03	30	30.08	17.26	1.95
Grubby	1.00	0.15	0.76	R04	43	1.34	16.43	3.30
Grubby	1.00	0.15	0.54	R04	44	1.34	3.36	1.65
Grubby	1.00	0.15	0.13	R04	45	1.34	0.00	0.00
Grubby	1.00	0.15	0.16	R05	52	26.81	1.49	0.00
Grubby	1.00	0.15	0.63	R05	53	26.81	23.11	5.59
Grubby	1.00	0.15	0.94	R05	54	26.81	1.76	3.58
Grubby	1.00	0.15	0.70	R06	67	4.15	7.32	5.21
Grubby	1.00	0.15	0.21	R06	68	4.15	6.55	1.50
Grubby	1.00	0.15	0.13	R06	69	4.15	4.18	2.85
Grubby	1.00	0.15	0.18	R07	76	22.69	1.13	2.37
Grubby	1.00	0.15	0.96	R07	77	22.69	12.02	7.64
Grubby	1.00	0.15	0.62	R07	78	22.69	3.59	1.82
Grubby	1.00	0.15	0.59	R08	102	10.21	0.00	0.00
Grubby	1.00	0.15	0.48	R08	103	10.21	1.55	3.06
Grubby	1.00	0.15	0.16	R08	104	10.21	2.79	2.78

Table B-1 (continued)
Entrainment data collected at the Sakonnet River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Grubby	1.00	0.15	0.20	R09	105	4.46	0.00	0.00
Grubby	1.00	0.15	0.48	R09	106	4.46	1.64	3.36
Grubby	1.00	0.15	0.51	R09	107	4.46	0.00	1.71
Grubby	1.00	0.15	0.71	R09	108	2.12	3.34	3.39
Grubby	1.00	0.15	0.33	R10	115	2.17	1.58	1.58
Grubby	1.00	0.15	0.06	R10	116	2.17	0.00	0.00
Grubby	1.00	0.30	0.15	R01	9	8.86	14.73	4.96
Grubby	1.00	0.30	0.50	R01	119	0.87	4.60	0.00
Grubby	1.00	0.30	0.47	R01	120	0.87	1.47	0.76
Grubby	1.00	0.30	0.09	R02	16	61.90	9.51	4.17
Grubby	1.00	0.30	1.02	R02	17	61.90	77.25	34.10
Grubby	1.00	0.30	0.69	R02	18	61.90	31.88	13.04
Grubby	1.00	0.30	0.63	R03	31	3.16	12.62	0.00
Grubby	1.00	0.30	0.62	R03	32	3.16	1.92	1.95
Grubby	1.00	0.30	0.47	R03	33	3.16	5.51	1.61
Grubby	1.00	0.30	0.16	R04	40	5.38	10.17	6.09
Grubby	1.00	0.30	0.67	R04	41	5.38	11.36	13.67
Grubby	1.00	0.30	0.84	R04	42	5.38	14.31	7.04
Grubby	1.00	0.30	0.97	R05	55	11.09	13.28	3.39
Grubby	1.00	0.30	0.50	R05	56	11.09	0.00	0.00
Grubby	1.00	0.30	0.06	R05	57	11.09	0.74	0.76
Grubby	1.00	0.30	0.04	R06	64	7.62	1.60	0.00
Grubby	1.00	0.30	0.30	R06	65	7.62	4.80	4.07
Grubby	1.00	0.30	0.88	R06	66	7.62	6.73	6.13
Grubby	1.00	0.30	0.58	R07	79	0.00	0.67	1.39
Grubby	1.00	0.30	0.04	R07	81	0.00	0.85	0.88
Grubby	1.00	0.30	0.44	R08	100	0.00	1.64	1.67
Grubby	1.00	0.30	0.66	R09	109	2.12	2.49	1.71
Grubby	1.00	0.30	0.12	R09	110	2.12	1.63	0.00
Grubby	1.00	0.30	0.38	R10	111	0.00	0.00	0.79
Grubby	1.00	0.30	0.53	R10	113	0.00	2.48	0.00
Grubby	1.00	0.30	0.44	R10	114	2.17	3.24	4.08
Longhorn Sculpin	0.50	0.15	0.59	R02	13	0.00	4.69	0.00
Longhorn Sculpin	1.00	0.15	0.54	R01	7	0.00	1.62	0.00
Longhorn Sculpin	1.00	0.15	0.29	R03	28	2.01	0.00	0.00
Longhorn Sculpin	1.00	0.15	1.02	R03	29	2.01	0.00	0.00
Longhorn Sculpin	1.00	0.15	0.95	R03	30	2.01	13.42	0.00
Longhorn Sculpin	1.00	0.15	0.63	R05	53	0.00	1.78	0.00
Rock Gunnel	0.50	0.15	0.69	R01	1	0.00	1.32	0.00

Table B-1 (continued)
Entrainment data collected at the Sakonnet River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Rock Gunnel	0.50	0.15	0.59	R02	13	0.00	2.35	0.00
Rock Gunnel	0.50	0.15	0.14	R03	22	3.53	0.00	0.00
Rock Gunnel	0.50	0.15	0.79	R03	23	3.53	0.00	0.00
Rock Gunnel	0.50	0.15	0.73	R03	24	3.53	0.00	0.00
Rock Gunnel	0.50	0.15	0.76	R04	37	0.75	0.00	0.00
Rock Gunnel	0.50	0.15	0.62	R04	38	0.75	0.00	0.00
Rock Gunnel	0.50	0.15	0.23	R04	39	0.75	0.00	0.00
Rock Gunnel	0.50	0.30	0.14	R02	10	0.00	1.40	0.00
Rock Gunnel	0.50	0.30	0.73	R02	11	0.00	0.91	0.00
Rock Gunnel	0.50	0.30	0.99	R02	12	0.00	1.20	0.00
Rock Gunnel	0.50	0.30	0.23	R04	34	1.80	0.00	0.00
Rock Gunnel	0.50	0.30	0.95	R04	35	1.80	0.00	0.00
Rock Gunnel	0.50	0.30	0.95	R04	36	1.80	0.00	0.00
Rock Gunnel	1.00	0.30	0.15	R01	9	0.00	0.98	0.00
Rock Gunnel	1.00	0.30	0.09	R02	16	7.74	0.00	0.00
Rock Gunnel	1.00	0.30	1.02	R02	17	7.74	0.90	0.00
Rock Gunnel	1.00	0.30	0.69	R02	18	7.74	0.00	0.00
Rock Gunnel	1.00	0.30	0.63	R03	31	3.16	0.00	0.00
Rock Gunnel	1.00	0.30	0.62	R03	32	3.16	0.00	0.00
Rock Gunnel	1.00	0.30	0.47	R03	33	3.16	0.00	0.00
Sand Lance	0.50	0.15	0.69	R01	1	42.29	30.40	4.96
Sand Lance	0.50	0.15	0.93	R01	2	42.29	29.22	1.48
Sand Lance	0.50	0.15	0.76	R01	3	42.29	28.42	4.13
Sand Lance	0.50	0.15	0.59	R02	13	106.75	75.10	0.00
Sand Lance	0.50	0.15	0.42	R02	14	106.75	39.99	1.80
Sand Lance	0.50	0.15	0.21	R02	15	106.75	14.88	0.00
Sand Lance	0.50	0.15	0.14	R03	22	367.60	60.87	0.00
Sand Lance	0.50	0.15	0.79	R03	23	367.60	465.92	30.84
Sand Lance	0.50	0.15	0.73	R03	24	367.60	372.66	24.93
Sand Lance	0.50	0.15	0.76	R04	37	50.52	15.54	3.93
Sand Lance	0.50	0.15	0.62	R04	38	50.52	5.08	4.78
Sand Lance	0.50	0.15	0.23	R04	39	50.52	0.00	0.00
Sand Lance	0.50	0.15	0.16	R05	46	167.15	3.51	1.64
Sand Lance	0.50	0.15	0.53	R05	47	167.15	42.03	4.09
Sand Lance	0.50	0.15	0.64	R05	48	167.15	67.17	2.96
Sand Lance	0.50	0.15	0.62	R06	61	0.00	3.04	0.00
Sand Lance	0.50	0.15	0.15	R07	70	59.66	0.00	0.00
Sand Lance	0.50	0.15	0.82	R07	71	59.66	1.36	0.00
Sand Lance	0.50	0.15	0.74	R07	72	59.66	0.00	0.00

Table B-1 (continued)
Entrainment data collected at the Sakonnet River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Sand Lance	0.50	0.15	0.47	R08	85	0.00	10.83	0.00
Sand Lance	0.50	0.15	0.21	R08	86	0.00	5.07	0.00
Sand Lance	0.50	0.15	0.03	R08	87	0.00	3.62	0.00
Sand Lance	0.50	0.15	0.17	R09	88	20.63	0.00	1.71
Sand Lance	0.50	0.15	0.70	R09	89	20.63	0.00	0.00
Sand Lance	0.50	0.15	0.49	R09	90	20.63	0.00	0.00
Sand Lance	0.50	0.30	0.47	R01	4	0.00	33.41	2.96
Sand Lance	0.50	0.30	0.02	R01	5	0.00	2.37	0.00
Sand Lance	0.50	0.30	0.05	R01	121	5.22	1.64	0.74
Sand Lance	0.50	0.30	0.14	R02	10	176.48	64.44	2.47
Sand Lance	0.50	0.30	0.73	R02	11	176.48	131.23	26.68
Sand Lance	0.50	0.30	0.99	R02	12	176.48	144.04	40.70
Sand Lance	0.50	0.30	0.35	R03	25	8.66	10.20	0.00
Sand Lance	0.50	0.30	0.36	R03	26	8.66	25.93	2.25
Sand Lance	0.50	0.30	0.15	R03	27	8.66	21.42	1.49
Sand Lance	0.50	0.30	0.23	R04	34	187.00	17.81	5.75
Sand Lance	0.50	0.30	0.95	R04	35	187.00	81.54	3.56
Sand Lance	0.50	0.30	0.95	R04	36	187.00	20.42	0.00
Sand Lance	0.50	0.30	0.60	R05	49	48.80	53.93	4.51
Sand Lance	0.50	0.30	0.29	R05	50	48.80	0.95	3.59
Sand Lance	0.50	0.30	0.07	R05	51	48.80	5.90	6.53
Sand Lance	0.50	0.30	0.24	R06	58	603.18	17.40	25.48
Sand Lance	0.50	0.30	0.87	R06	59	603.18	53.02	1.72
Sand Lance	0.50	0.30	0.96	R06	60	603.18	7.58	0.00
Sand Lance	0.50	0.30	0.46	R07	73	19.03	1.76	0.00
Sand Lance	0.50	0.30	0.20	R07	74	19.03	0.00	0.00
Sand Lance	0.50	0.30	0.02	R07	75	19.03	0.00	0.78
Sand Lance	0.50	0.30	0.05	R08	82	34.68	0.00	3.10
Sand Lance	0.50	0.30	0.25	R08	83	34.68	5.21	1.41
Sand Lance	0.50	0.30	0.71	R08	84	34.68	30.18	0.00
Sand Lance	0.50	0.30	0.44	R09	91	0.00	1.90	0.88
Sand Lance	0.50	0.30	0.52	R10	94		1.74	0.00
Sand Lance	0.50	0.30	0.81	R10	95		0.83	0.00
Sand Lance	1.00	0.15	0.85	R01	6	8.86	51.08	33.06
Sand Lance	1.00	0.15	0.54	R01	7	8.86	55.12	55.29
Sand Lance	1.00	0.15	0.30	R01	8	8.86	16.85	34.79
Sand Lance	1.00	0.15	0.30	R01	117	6.95	0.00	0.00
Sand Lance	1.00	0.15	0.77	R01	118	6.95	16.89	6.36
Sand Lance	1.00	0.15	0.41	R02	19	14.88	28.66	15.32

Table B-1 (continued)
Entrainment data collected at the Sakonnet River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Sand Lance	1.00	0.15	0.23	R02	20	14.88	9.22	3.75
Sand Lance	1.00	0.15	0.29	R02	21	14.88	7.00	1.75
Sand Lance	1.00	0.15	0.29	R03	28	281.72	3.06	2.70
Sand Lance	1.00	0.15	1.02	R03	29	281.72	36.35	53.29
Sand Lance	1.00	0.15	0.95	R03	30	281.72	51.77	62.45
Sand Lance	1.00	0.15	0.76	R04	43	142.41	19.72	56.10
Sand Lance	1.00	0.15	0.54	R04	44	142.41	1.68	14.89
Sand Lance	1.00	0.15	0.13	R04	45	142.41	10.47	7.54
Sand Lance	1.00	0.15	0.16	R05	52	147.43	0.00	3.12
Sand Lance	1.00	0.15	0.63	R05	53	147.43	3.56	16.78
Sand Lance	1.00	0.15	0.94	R05	54	147.43	61.58	82.37
Sand Lance	1.00	0.15	0.70	R06	67	85.18	4.88	14.33
Sand Lance	1.00	0.15	0.21	R06	68	85.18	0.00	12.02
Sand Lance	1.00	0.15	0.13	R06	69	85.18	0.00	1.42
Sand Lance	1.00	0.15	0.18	R07	76	215.60	1.13	0.00
Sand Lance	1.00	0.15	0.96	R07	77	215.60	3.00	1.53
Sand Lance	1.00	0.15	0.62	R07	78	215.60	0.00	0.00
Sand Lance	1.00	0.15	0.59	R08	102	1.46	0.00	0.00
Sand Lance	1.00	0.15	0.48	R08	103	1.46	3.10	1.53
Sand Lance	1.00	0.15	0.16	R08	104	1.46	0.00	0.00
Sand Lance	1.00	0.15	0.20	R09	105	23.42	0.00	0.00
Sand Lance	1.00	0.15	0.48	R09	106	23.42	0.00	0.00
Sand Lance	1.00	0.15	0.51	R09	107	23.42	0.00	0.00
Sand Lance	1.00	0.15	0.71	R09	108	5.30	3.34	0.00
Sand Lance	1.00	0.15	0.33	R10	115	17.35	0.00	1.58
Sand Lance	1.00	0.15	0.06	R10	116	17.35	11.27	0.00
Sand Lance	1.00	0.30	0.15	R01	9	8.86	41.25	3.97
Sand Lance	1.00	0.30	0.50	R01	119	5.22	16.09	5.58
Sand Lance	1.00	0.30	0.47	R01	120	5.22	30.08	3.04
Sand Lance	1.00	0.30	0.09	R02	16	358.49	22.18	9.16
Sand Lance	1.00	0.30	1.02	R02	17	358.49	172.46	80.51
Sand Lance	1.00	0.30	0.69	R02	18	358.49	39.07	17.39
Sand Lance	1.00	0.30	0.63	R03	31	20.56	16.82	8.07
Sand Lance	1.00	0.30	0.62	R03	32	20.56	8.64	13.67
Sand Lance	1.00	0.30	0.47	R03	33	20.56	11.03	9.69
Sand Lance	1.00	0.30	0.16	R04	40	79.65	16.95	20.70
Sand Lance	1.00	0.30	0.67	R04	41	79.65	9.29	141.97
Sand Lance	1.00	0.30	0.84	R04	42	79.65	35.36	79.22
Sand Lance	1.00	0.30	0.97	R05	55	99.85	33.20	18.64

Table B-1 (continued)
Entrainment data collected at the Sakonnet River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Sand Lance	1.00	0.30	0.50	R05	56	99.85	2.58	4.45
Sand Lance	1.00	0.30	0.06	R05	57	99.85	5.94	26.49
Sand Lance	1.00	0.30	0.04	R06	64	294.30	1.60	0.00
Sand Lance	1.00	0.30	0.30	R06	65	294.30	20.16	33.61
Sand Lance	1.00	0.30	0.88	R06	66	294.30	63.08	70.05
Sand Lance	1.00	0.30	0.58	R07	79	33.55	0.67	0.70
Sand Lance	1.00	0.30	0.35	R07	80	33.55	0.00	0.84
Sand Lance	1.00	0.30	0.04	R07	81	33.55	0.85	0.88
Sand Lance	1.00	0.30	0.09	R08	99	1.32	0.00	0.00
Sand Lance	1.00	0.30	0.44	R08	100	1.32	0.00	0.00
Sand Lance	1.00	0.30	0.67	R08	101	1.32	0.00	0.00
Sand Lance	1.00	0.30	0.66	R09	109	5.30	14.93	3.41
Sand Lance	1.00	0.30	0.12	R09	110	5.30	2.45	0.00
Sand Lance	1.00	0.30	0.38	R10	111	188.82	0.77	0.79
Sand Lance	1.00	0.30	0.59	R10	112	188.82	0.00	0.00
Sand Lance	1.00	0.30	0.53	R10	113	188.82	24.01	2.58
Sand Lance	1.00	0.30	0.44	R10	114	17.35	6.47	15.50
Sculpin spp.	1.00	0.30	0.58	R07	79	0.00	2.67	0.00
Tautog	0.50	0.15	0.47	R08	85	6.92	0.00	0.00
Tautog	0.50	0.15	0.21	R08	86	6.92	0.00	0.00
Tautog	0.50	0.15	0.03	R08	87	6.92	0.00	0.00
Tautog	0.50	0.30	0.23	R04	34	0.90	0.00	0.00
Tautog	0.50	0.30	0.95	R04	35	0.90	0.00	0.00
Tautog	0.50	0.30	0.95	R04	36	0.90	0.00	0.00
Unknown	0.50	0.15	0.69	R01	1	38.41	0.00	28.55
Unknown	0.50	0.15	0.93	R01	2	38.41	0.00	0.00
Unknown	0.50	0.15	0.76	R01	3	38.41	0.00	0.00
Unknown	0.50	0.15	0.79	R03	23	0.00	0.00	1.47
Unknown	0.50	0.15	0.62	R06	61	0.00	0.00	4.36
Unknown	0.50	0.15	0.21	R08	86	0.00	0.00	1.58
Unknown	0.50	0.15	0.49	R09	90	0.00	0.00	1.61
Unknown	0.50	0.30	0.87	R06	59	0.00	1.86	4.31
Unknown	0.50	0.30	0.96	R06	60	0.00	0.00	2.94
Unknown	0.50	0.30	0.46	R07	73	0.00	0.00	0.80
Unknown	1.00	0.15	0.30	R01	117	0.99	0.00	0.00
Unknown	1.00	0.15	0.77	R01	118	0.99	0.00	0.00
Unknown	1.00	0.15	0.41	R02	19	0.00	0.00	3.40
Unknown	1.00	0.15	0.29	R03	28	0.00	0.00	2.70
Unknown	1.00	0.15	0.76	R04	43	1.34	0.00	0.00

Table B-1 (continued)
Entrainment data collected at the Sakonnet River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Unknown	1.00	0.15	0.54	R04	44	1.34	0.00	0.00
Unknown	1.00	0.15	0.13	R04	45	1.34	0.00	0.00
Unknown	1.00	0.15	0.16	R08	104	0.00	1.39	0.00
Unknown	1.00	0.30	0.50	R01	119	0.00	0.00	7.17
Unknown	1.00	0.30	0.47	R01	120	0.00	0.00	6.09
Unknown	1.00	0.30	0.09	R02	16	0.00	0.00	0.83
Unknown	1.00	0.30	0.69	R02	18	0.00	14.40	0.00
Unknown	1.00	0.30	0.16	R04	40	1.08	0.00	0.00
Unknown	1.00	0.30	0.67	R04	41	1.08	0.00	1.05
Unknown	1.00	0.30	0.84	R04	42	1.08	11.79	0.00
Unknown	1.00	0.30	0.35	R07	80	0.00	0.00	0.84
Winter Flounder	0.50	0.15	0.69	R01	1	0.00	47.59	0.00
Winter Flounder	0.50	0.15	0.93	R01	2	0.00	85.01	20.70
Winter Flounder	0.50	0.15	0.76	R01	3	0.00	62.53	56.38
Winter Flounder	0.50	0.15	0.59	R02	13	46.70	35.20	12.74
Winter Flounder	0.50	0.15	0.42	R02	14	46.70	24.44	0.00
Winter Flounder	0.50	0.15	0.21	R02	15	46.70	20.46	8.72
Winter Flounder	0.50	0.15	0.14	R03	22	40.65	46.37	17.66
Winter Flounder	0.50	0.15	0.79	R03	23	40.65	86.28	36.72
Winter Flounder	0.50	0.15	0.73	R03	24	40.65	74.53	41.06
Winter Flounder	0.50	0.15	0.76	R04	37	46.75	22.44	15.72
Winter Flounder	0.50	0.15	0.62	R04	38	46.75	21.99	4.78
Winter Flounder	0.50	0.15	0.23	R04	39	46.75	16.93	14.88
Winter Flounder	0.50	0.15	0.16	R05	46	52.23	7.01	3.29
Winter Flounder	0.50	0.15	0.53	R05	47	52.23	34.78	9.55
Winter Flounder	0.50	0.15	0.64	R05	48	52.23	38.38	26.68
Winter Flounder	0.50	0.15	0.62	R06	61	13.24	5.06	0.00
Winter Flounder	0.50	0.15	0.14	R06	62	13.24	0.00	1.41
Winter Flounder	0.50	0.15	0.04	R06	63	13.24	9.09	0.00
Winter Flounder	0.50	0.15	0.15	R07	70	39.77	7.86	0.00
Winter Flounder	0.50	0.15	0.82	R07	71	39.77	13.61	12.50
Winter Flounder	0.50	0.15	0.74	R07	72	39.77	9.38	3.67
Winter Flounder	0.50	0.15	0.47	R08	85	41.53	26.29	1.54
Winter Flounder	0.50	0.15	0.21	R08	86	41.53	16.89	3.16
Winter Flounder	0.50	0.15	0.03	R08	87	41.53	5.42	1.66
Winter Flounder	0.50	0.15	0.17	R09	88	14.57	0.00	0.00
Winter Flounder	0.50	0.15	0.70	R09	89	14.57	18.99	0.00
Winter Flounder	0.50	0.15	0.49	R09	90	14.57	10.55	0.00
Winter Flounder	0.50	0.15	0.21	R10	96	0.00	1.89	1.68

Table B-1 (continued)
Entrainment data collected at the Sakonnet River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Winter Flounder	0.50	0.15	0.47	R10	97	0.00	0.00	1.53
Winter Flounder	0.50	0.30	0.47	R01	4	355.40	49.35	40.71
Winter Flounder	0.50	0.30	0.02	R01	5	355.40	10.26	11.31
Winter Flounder	0.50	0.30	0.05	R01	121	34.81	15.56	5.93
Winter Flounder	0.50	0.30	0.14	R02	10	38.26	14.01	12.35
Winter Flounder	0.50	0.30	0.73	R02	11	38.26	44.66	21.67
Winter Flounder	0.50	0.30	0.99	R02	12	38.26	30.01	27.50
Winter Flounder	0.50	0.30	0.35	R03	25	43.28	7.06	5.15
Winter Flounder	0.50	0.30	0.36	R03	26	43.28	15.40	3.75
Winter Flounder	0.50	0.30	0.15	R03	27	43.28	3.17	4.47
Winter Flounder	0.50	0.30	0.23	R04	34	44.05	17.81	12.45
Winter Flounder	0.50	0.30	0.95	R04	35	44.05	47.64	20.45
Winter Flounder	0.50	0.30	0.95	R04	36	44.05	24.51	20.42
Winter Flounder	0.50	0.30	0.60	R05	49	73.20	37.95	0.00
Winter Flounder	0.50	0.30	0.29	R05	50	73.20	7.59	3.59
Winter Flounder	0.50	0.30	0.07	R05	51	73.20	9.26	2.45
Winter Flounder	0.50	0.30	0.24	R06	58	36.43	26.97	17.51
Winter Flounder	0.50	0.30	0.87	R06	59	36.43	40.00	0.00
Winter Flounder	0.50	0.30	0.96	R06	60	36.43	16.12	6.86
Winter Flounder	0.50	0.30	0.46	R07	73	38.05	6.17	0.80
Winter Flounder	0.50	0.30	0.20	R07	74	38.05	8.25	1.77
Winter Flounder	0.50	0.30	0.02	R07	75	38.05	8.31	6.21
Winter Flounder	0.50	0.30	0.05	R08	82	86.69	18.24	32.20
Winter Flounder	0.50	0.30	0.25	R08	83	86.69	31.28	4.24
Winter Flounder	0.50	0.30	0.71	R08	84	86.69	30.18	7.22
Winter Flounder	0.50	0.30	0.44	R09	91	27.79	2.85	0.88
Winter Flounder	0.50	0.30	0.29	R09	92	27.79	0.00	0.00
Winter Flounder	0.50	0.30	0.07	R09	122		0.81	0.00
Winter Flounder	0.50	0.30	0.05	R10	93		3.25	2.18
Winter Flounder	0.50	0.30	0.52	R10	94		3.48	0.00
Winter Flounder	0.50	0.30	0.81	R10	95		2.50	0.00
Winter Flounder	1.00	0.15	0.85	R01	6	70.89	0.00	58.50
Winter Flounder	1.00	0.15	0.54	R01	7	70.89	40.53	14.94
Winter Flounder	1.00	0.15	0.30	R01	8	70.89	22.47	34.79
Winter Flounder	1.00	0.15	0.30	R01	117	21.83	4.69	6.44
Winter Flounder	1.00	0.15	0.77	R01	118	21.83	13.82	11.14
Winter Flounder	1.00	0.15	0.41	R02	19	104.16	28.66	15.32
Winter Flounder	1.00	0.15	0.23	R02	20	104.16	5.53	3.75
Winter Flounder	1.00	0.15	0.29	R02	21	104.16	0.00	1.75

Table B-1 (continued)
Entrainment data collected at the Sakonnet River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Winter Flounder	1.00	0.15	0.29	R03	28	55.14	6.13	5.41
Winter Flounder	1.00	0.15	1.02	R03	29	55.14	36.35	76.13
Winter Flounder	1.00	0.15	0.95	R03	30	55.14	51.77	40.99
Winter Flounder	1.00	0.15	0.76	R04	43	57.77	49.29	34.65
Winter Flounder	1.00	0.15	0.54	R04	44	57.77	18.48	18.19
Winter Flounder	1.00	0.15	0.13	R04	45	57.77	13.96	13.19
Winter Flounder	1.00	0.15	0.16	R05	52	60.31	20.83	14.03
Winter Flounder	1.00	0.15	0.63	R05	53	60.31	16.00	18.64
Winter Flounder	1.00	0.15	0.94	R05	54	60.31	36.95	35.81
Winter Flounder	1.00	0.15	0.70	R06	67	97.64	29.28	40.38
Winter Flounder	1.00	0.15	0.21	R06	68	97.64	4.91	18.04
Winter Flounder	1.00	0.15	0.13	R06	69	97.64	5.57	9.97
Winter Flounder	1.00	0.15	0.18	R07	76	31.21	4.54	3.55
Winter Flounder	1.00	0.15	0.96	R07	77	31.21	7.51	21.39
Winter Flounder	1.00	0.15	0.62	R07	78	31.21	1.80	14.58
Winter Flounder	1.00	0.15	0.59	R08	102	121.06	17.12	15.90
Winter Flounder	1.00	0.15	0.48	R08	103	121.06	44.95	22.96
Winter Flounder	1.00	0.15	0.16	R08	104	121.06	50.21	18.04
Winter Flounder	1.00	0.15	0.20	R09	105	39.04	7.57	3.06
Winter Flounder	1.00	0.15	0.48	R09	106	39.04	13.14	18.45
Winter Flounder	1.00	0.15	0.51	R09	107	39.04	6.80	18.79
Winter Flounder	1.00	0.15	0.71	R09	108	70.02	40.06	47.47
Winter Flounder	1.00	0.15	0.33	R10	115	63.98	15.77	12.61
Winter Flounder	1.00	0.15	0.06	R10	116	63.98	22.55	9.64
Winter Flounder	1.00	0.30	0.15	R01	9	70.89	63.83	15.88
Winter Flounder	1.00	0.30	0.50	R01	119	34.81	16.09	0.00
Winter Flounder	1.00	0.30	0.47	R01	120	34.81	27.88	2.28
Winter Flounder	1.00	0.30	0.09	R02	16	59.32	11.88	3.33
Winter Flounder	1.00	0.30	1.02	R02	17	59.32	42.22	27.47
Winter Flounder	1.00	0.30	0.69	R02	18	59.32	12.34	14.13
Winter Flounder	1.00	0.30	0.63	R03	31	17.40	29.44	16.14
Winter Flounder	1.00	0.30	0.62	R03	32	17.40	3.84	12.69
Winter Flounder	1.00	0.30	0.47	R03	33	17.40	18.11	11.30
Winter Flounder	1.00	0.30	0.16	R04	40	26.91	14.69	42.61
Winter Flounder	1.00	0.30	0.67	R04	41	26.91	12.39	55.74
Winter Flounder	1.00	0.30	0.84	R04	42	26.91	11.79	52.81
Winter Flounder	1.00	0.30	0.97	R05	55	16.64	11.62	10.17
Winter Flounder	1.00	0.30	0.50	R05	56	16.64	5.16	7.12
Winter Flounder	1.00	0.30	0.06	R05	57	16.64	5.20	13.62

Table B-1 (continued)
Entrainment data collected at the Sakonnet River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Winter Flounder	1.00	0.30	0.04	R06	64	39.65	6.42	4.13
Winter Flounder	1.00	0.30	0.30	R06	65	39.65	16.32	10.19
Winter Flounder	1.00	0.30	0.88	R06	66	39.65	21.87	8.76
Winter Flounder	1.00	0.30	0.58	R07	79	4.79	0.67	2.09
Winter Flounder	1.00	0.30	0.35	R07	80	4.79	4.85	0.00
Winter Flounder	1.00	0.30	0.04	R07	81	4.79	1.71	0.00
Winter Flounder	1.00	0.30	0.09	R08	99	26.48	2.50	2.65
Winter Flounder	1.00	0.30	0.44	R08	100	26.48	1.64	3.34
Winter Flounder	1.00	0.30	0.67	R08	101	26.48	1.73	2.68
Winter Flounder	1.00	0.30	0.66	R09	109	70.02	18.25	7.67
Winter Flounder	1.00	0.30	0.12	R09	110	70.02	30.16	19.46
Winter Flounder	1.00	0.30	0.38	R10	111	24.68	3.07	0.79
Winter Flounder	1.00	0.30	0.59	R10	112	24.68	8.12	0.00
Winter Flounder	1.00	0.30	0.53	R10	113	24.68	21.53	13.76
Winter Flounder	1.00	0.30	0.44	R10	114	63.98	10.51	9.79

C
ENTRAINMENT DATA – FRESHWATER TESTING

Table C-1
Entrainment data collected at the Portage River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Bluntnose Minnows	1.00	0.15	0.03	R02	130	0.00	0.47	0.00
Bluntnose Minnows	1.00	0.30	0.09	R05	142	11.11	0.00	0.00
Bullhead Minnow	0.50	0.30	0.02	R03	132	0.00	0.00	1.03
Bullhead Minnow	1.00	0.15	0.07	R01	125	2.35	0.00	0.00
Bullhead Minnow	1.00	0.15	0.03	R02	130	0.00	0.00	1.34
Bullhead Minnow	1.00	0.15	0.01	R08	154	0.00	1.20	0.00
Carp spp.	0.50	0.15	0.01	R01	123	0.00	0.00	0.36
Carp spp.	0.50	0.15	0.01	R03	131	0.00	17.03	21.87
Carp spp.	0.50	0.15	0.07	R04	136	2.82	0.00	0.52
Carp spp.	0.50	0.15	0.05	R05	139	0.00	1.59	0.00
Carp spp.	0.50	0.15	0.00	R07	147	0.00	0.44	0.40
Carp spp.	0.50	0.15	0.02	R08	152	0.00	0.87	0.00
Carp spp.	0.50	0.15	0.07	R09	155	0.00	0.00	1.17
Carp spp.	0.50	0.30	0.07	R01	124	0.00	0.00	1.15
Carp spp.	0.50	0.30	0.02	R03	132	0.00	0.00	0.62
Carp spp.	0.50	0.30	0.02	R04	135	0.00	6.51	2.01
Carp spp.	0.50	0.30	0.05	R05	140	0.00	0.86	0.00
Carp spp.	0.50	0.30	0.06	R06	143	0.00	0.00	3.33
Carp spp.	0.50	0.30	0.14	R09	156	0.00	7.16	4.17
Carp spp.	1.00	0.15	0.07	R01	125	0.00	1.28	0.00
Carp spp.	1.00	0.15	0.03	R02	130	5.63	0.00	0.45
Carp spp.	1.00	0.15	0.09	R03	133	0.00	0.87	0.83
Carp spp.	1.00	0.15	0.16	R04	138	0.00	0.00	1.71
Carp spp.	1.00	0.15	0.07	R05	141	0.00	0.00	1.64
Carp spp.	1.00	0.15	0.01	R08	154	0.00	1.20	0.00
Carp spp.	1.00	0.15	0.11	R09	157	19.67	6.92	10.37
Carp spp.	1.00	0.15	0.01	R10	162	0.00	10.51	0.00
Carp spp.	1.00	0.30	0.02	R02	129	0.00	1.32	0.45
Carp spp.	1.00	0.30	0.13	R03	134	0.00	2.68	0.66
Carp spp.	1.00	0.30	0.06	R04	137	0.00	3.36	1.13

Table C-1 (continued)
Entrainment data collected at the Portage River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Carp spp.	1.00	0.30	0.09	R05	142	44.46	27.79	14.70
Carp spp.	1.00	0.30	0.14	R06	145	0.00	0.89	0.45
Carp spp.	1.00	0.30	0.13	R09	158	66.85	14.59	7.34
Carp spp.	1.00	0.30	0.03	R10	161	0.00	3.48	0.00
Crappies	0.50	0.15	0.01	R03	131	5.73	1.70	0.00
Crappies	0.50	0.15	0.02	R08	152	0.00	0.87	0.40
Crappies	0.50	0.15	0.07	R09	155	12.70	0.86	0.00
Crappies	0.50	0.30	0.06	R02	127	0.00	0.88	0.00
Crappies	0.50	0.30	0.02	R04	135	0.00	0.87	0.00
Crappies	0.50	0.30	0.09	R07	148	0.00	0.93	0.00
Crappies	0.50	0.30	0.14	R09	156	0.00	10.74	1.67
Crappies	1.00	0.15	0.03	R02	130	0.00	0.47	0.45
Crappies	1.00	0.15	0.09	R03	133	2.68	0.00	0.00
Crappies	1.00	0.15	0.16	R04	138	0.00	1.70	0.00
Crappies	1.00	0.15	0.05	R07	149	22.64	0.00	0.00
Crappies	1.00	0.30	0.02	R01	126	0.00	0.88	0.69
Crappies	1.00	0.30	0.13	R03	134	0.00	0.89	0.22
Crappies	1.00	0.30	0.06	R04	137	1.57	3.36	0.57
Crappies	1.00	0.30	0.01	R08	153	0.00	0.43	0.00
Crappies	1.00	0.30	0.03	R10	161	0.00	1.74	0.00
Darters spp.	0.50	0.30	0.09	R08	151	6.30	0.00	0.00
Darters spp.	1.00	0.30	0.02	R01	126	0.00	0.00	0.23
eggs	0.50	0.15	0.01	R01	123	0.00	1.54	0.72
eggs	0.50	0.15	0.07	R04	136	31.01	3.36	0.52
eggs	0.50	0.15	0.01	R06	144	230.23	238.86	9.83
eggs	0.50	0.15	0.00	R07	147	52.87	30.18	0.40
eggs	0.50	0.15	0.02	R08	152	0.00	5.66	0.00
eggs	0.50	0.15	0.07	R09	155	25.40	24.92	0.00
eggs	0.50	0.15	0.12	R10	160	383.99	146.83	0.00
eggs	0.50	0.30	0.07	R01	124	0.00	2.33	0.00
eggs	0.50	0.30	0.06	R02	127	0.00	0.00	0.27
eggs	0.50	0.30	0.02	R03	132	0.00	2.44	0.21
eggs	0.50	0.30	0.02	R04	135	5.26	16.93	2.82
eggs	0.50	0.30	0.05	R05	140	35.15	47.89	1.59
eggs	0.50	0.30	0.06	R06	143	67.88	50.29	4.99
eggs	0.50	0.30	0.09	R07	148	4.69	4.65	0.87
eggs	0.50	0.30	0.09	R08	151	25.20	17.64	3.47
eggs	0.50	0.30	0.14	R09	156	128.40	10.74	14.18
eggs	0.50	0.30	0.00	R10	159	648.12	266.71	0.00

Table C-1 (continued)
Entrainment data collected at the Portage River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
eggs	1.00	0.15	0.07	R01	125	4.69	7.26	1.24
eggs	1.00	0.15	0.03	R02	130	0.00	15.14	1.34
eggs	1.00	0.15	0.09	R03	133	0.00	0.43	3.31
eggs	1.00	0.15	0.16	R04	138	18.16	7.63	2.86
eggs	1.00	0.15	0.07	R05	141	291.25	632.29	19.71
eggs	1.00	0.15	0.09	R06	146	90.24	1.80	1.36
eggs	1.00	0.15	0.05	R07	149	22.64	2.54	5.19
eggs	1.00	0.15	0.01	R08	154	0.00	0.00	2.39
eggs	1.00	0.15	0.11	R09	157	295.03	190.24	0.00
eggs	1.00	0.15	0.01	R10	162	18.41	171.69	7.13
eggs	1.00	0.30	0.02	R01	126	0.00	2.65	2.54
eggs	1.00	0.30	0.02	R02	129	0.00	21.18	0.00
eggs	1.00	0.30	0.13	R03	134	12.09	0.00	1.33
eggs	1.00	0.30	0.06	R04	137	6.27	13.44	3.40
eggs	1.00	0.30	0.09	R05	142	1,522.60	472.38	446.66
eggs	1.00	0.30	0.14	R06	145	10.68	2.66	7.64
eggs	1.00	0.30	0.01	R07	150	2.11	0.00	0.00
eggs	1.00	0.30	0.01	R08	153	0.00	1.73	0.00
eggs	1.00	0.30	0.13	R09	158	5,698.70	601.90	488.09
eggs	1.00	0.30	0.03	R10	161	124.51	55.71	21.07
Emerald Shiner	0.50	0.15	0.01	R06	144	2.57	0.00	0.00
Emerald Shiner	0.50	0.15	0.07	R09	155	25.40	0.00	0.00
Emerald Shiner	1.00	0.15	0.01	R08	154	0.00	1.20	0.00
Emerald Shiner (Adult)	1.00	0.15	0.07	R01	125	21.11	0.00	0.00
Fathead Minnow	0.50	0.30	0.02	R03	132	0.00	1.78	0.00
Fathead Minnow	0.50	0.30	0.02	R04	135	0.00	0.87	0.00
Fathead Minnow	1.00	0.30	0.01	R07	150	2.11	0.00	0.00
Freshwater Drum	0.50	0.15	0.01	R06	144	20.58	10.78	16.38
Freshwater Drum	0.50	0.15	0.00	R07	147	2.11	0.00	0.40
Freshwater Drum	0.50	0.15	0.02	R08	152	0.00	5.23	0.40
Freshwater Drum	0.50	0.15	0.07	R09	155	0.00	0.86	0.00
Freshwater Drum	0.50	0.15	0.12	R10	160	12.69	16.31	0.00
Freshwater Drum	0.50	0.30	0.06	R06	143	13.58	14.37	4.99
Freshwater Drum	0.50	0.30	0.09	R08	151	0.00	3.53	0.00
Freshwater Drum	0.50	0.30	0.14	R09	156	417.28	7.16	0.83
Freshwater Drum	0.50	0.30	0.00	R10	159	0.00	117.01	0.00
Freshwater Drum	1.00	0.15	0.09	R06	146	0.00	0.00	0.91
Freshwater Drum	1.00	0.15	0.05	R07	149	0.00	0.00	0.87

Table C-1 (continued)
Entrainment data collected at the Portage River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Freshwater Drum	1.00	0.15	0.11	R09	157	137.68	0.00	0.00
Freshwater Drum	1.00	0.15	0.01	R10	162	6.91	220.74	197.88
Freshwater Drum	1.00	0.30	0.13	R09	158	133.69	36.48	12.84
Freshwater Drum	1.00	0.30	0.03	R10	161	1,660.16	52.23	12.29
Golden Shiner	1.00	0.15	0.01	R08	154	0.00	25.27	0.00
Golden Shiner	1.00	0.30	0.01	R08	153	0.00	0.00	0.85
Logperch	1.00	0.15	0.07	R01	125	2.35	0.00	0.00
Quillback Carpsucker	0.50	0.15	0.01	R01	123	1.48	0.00	0.00
Quillback Carpsucker	0.50	0.30	0.07	R01	124	0.00	0.00	0.38
Quillback Carpsucker	0.50	0.30	0.02	R03	132	0.00	3.55	0.00
Quillback Carpsucker	1.00	0.15	0.16	R04	138	1.65	0.00	0.00
Quillback Carpsucker	1.00	0.30	0.02	R01	126	0.00	0.00	0.23
Sculpin spp.	0.50	0.30	0.00	R10	159	0.00	1.72	0.00
Shad spp.	0.50	0.15	0.01	R01	123	37.09	0.00	3.22
Shad spp.	0.50	0.15	0.10	R02	128	776.87	100.39	47.04
Shad spp.	0.50	0.15	0.01	R03	131	1,454.59	509.11	698.33
Shad spp.	0.50	0.15	0.07	R04	136	566.66	178.94	88.45
Shad spp.	0.50	0.15	0.05	R05	139	813.03	178.30	94.68
Shad spp.	0.50	0.15	0.01	R06	144	72.03	3.59	248.91
Shad spp.	0.50	0.15	0.00	R07	147	137.45	92.72	17.36
Shad spp.	0.50	0.15	0.02	R08	152	1,131.36	31.37	14.12
Shad spp.	0.50	0.15	0.07	R09	155	6,272.59	88.53	39.73
Shad spp.	0.50	0.15	0.12	R10	160	263.40	154.08	48.78
Shad spp.	0.50	0.30	0.07	R01	124	2,201.84	54.26	209.11
Shad spp.	0.50	0.30	0.06	R02	127	555.74	221.59	190.01
Shad spp.	0.50	0.30	0.02	R03	132	21.96	56.87	14.40
Shad spp.	0.50	0.30	0.02	R04	135	159.43	119.39	113.58
Shad spp.	0.50	0.30	0.05	R05	140	627.71	135.97	65.36
Shad spp.	0.50	0.30	0.06	R06	143	1,506.88	467.02	412.67
Shad spp.	0.50	0.30	0.09	R07	148	179.61	97.61	11.69
Shad spp.	0.50	0.30	0.09	R08	151	195.28	458.51	18.17
Shad spp.	0.50	0.30	0.14	R09	156	7,832.11	526.05	45.46
Shad spp.	0.50	0.30	0.00	R10	159	602.30	306.29	152.92
Shad spp.	1.00	0.15	0.07	R01	125	640.36	289.25	68.18
Shad spp.	1.00	0.15	0.03	R02	130	78.82	57.71	116.11
Shad spp.	1.00	0.15	0.09	R03	133	377.52	104.52	26.50
Shad spp.	1.00	0.15	0.16	R04	138	186.51	86.52	43.99
Shad spp.	1.00	0.15	0.07	R05	141	651.04	602.81	261.19
Shad spp.	1.00	0.15	0.09	R06	146	5,098.42	71.53	67.71

Table C-1 (continued)
Entrainment data collected at the Portage River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Shad spp.	1.00	0.15	0.05	R07	149	2,309.67	38.06	15.58
Shad spp.	1.00	0.15	0.01	R08	154	182.52	32.49	123.27
Shad spp.	1.00	0.15	0.11	R09	157	8,555.81	3,092.20	2,994.13
Shad spp.	1.00	0.15	0.01	R10	162	416.63	231.25	1.78
Shad spp.	1.00	0.30	0.02	R01	126	149.67	202.45	148.24
Shad spp.	1.00	0.30	0.02	R02	129	687.21	101.48	67.64
Shad spp.	1.00	0.30	0.13	R03	134	755.52	191.21	25.24
Shad spp.	1.00	0.30	0.06	R04	137	335.71	238.63	75.91
Shad spp.	1.00	0.30	0.09	R05	142	2,789.58	1,055.91	942.94
Shad spp.	1.00	0.30	0.14	R06	145	774.08	65.57	54.83
Shad spp.	1.00	0.30	0.01	R07	150	629.94	1,577.50	1,827.49
Shad spp.	1.00	0.30	0.01	R08	153	22.18	112.96	0.00
Shad spp.	1.00	0.30	0.13	R09	158	3,994.10	822.60	603.69
Shad spp.	1.00	0.30	0.03	R10	161	298.83	886.11	1,032.42
Shiner spp.	0.50	0.15	0.10	R02	128	38.21	0.00	0.00
Shiner spp.	0.50	0.15	0.07	R04	136	0.00	0.00	1.05
Shiner spp.	1.00	0.30	0.14	R06	145	0.00	0.00	0.45
Shiner spp. (Adult)	1.00	0.15	0.09	R03	133	2.68	0.00	0.00
Shiners spp.	0.50	0.15	0.02	R08	152	0.00	0.00	0.40
Shiners spp.	0.50	0.30	0.02	R03	132	0.00	0.22	0.00
Shiners spp.	0.50	0.30	0.02	R04	135	0.00	0.00	0.40
Shiners spp.	1.00	0.15	0.01	R08	154	3.80	0.00	27.53
Shiners spp.	1.00	0.30	0.01	R08	153	2.02	2.60	0.00
Spottail Shiner	0.50	0.30	0.00	R10	159	6.55	0.00	0.00
Suckers	0.50	0.15	0.07	R09	155	0.00	0.00	1.56
Suckers	1.00	0.15	0.03	R02	130	0.00	0.47	0.00
Sunfish spp.	0.50	0.15	0.02	R08	152	0.00	0.44	0.00
Sunfish spp.	0.50	0.15	0.07	R09	155	25.40	0.00	0.00
Sunfish spp.	0.50	0.30	0.06	R06	143	13.58	0.00	0.00
Sunfish spp.	0.50	0.30	0.09	R08	151	0.00	3.53	0.00
Sunfish spp.	0.50	0.30	0.00	R10	159	0.00	3.44	0.00
Sunfish spp.	1.00	0.15	0.05	R07	149	0.00	0.85	0.00
Sunfish spp.	1.00	0.15	0.11	R09	157	0.00	0.00	6.91
Sunfish spp.	1.00	0.30	0.13	R09	158	0.00	1.82	0.00
Temperate basses	0.50	0.15	0.01	R03	131	0.00	0.00	3.12
Temperate basses	0.50	0.15	0.05	R05	139	0.00	1.59	0.00
Temperate basses	0.50	0.15	0.01	R06	144	9.00	16.16	0.00
Temperate basses	0.50	0.15	0.00	R07	147	6.34	0.44	0.00
Temperate basses	0.50	0.15	0.02	R08	152	67.54	2.18	0.40

Table C-1 (continued)
Entrainment data collected at the Portage River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Temperate basses	0.50	0.15	0.07	R09	155	50.79	6.88	0.00
Temperate basses	0.50	0.15	0.12	R10	160	12.69	3.63	1.22
Temperate basses	0.50	0.30	0.02	R04	135	3.50	0.00	0.00
Temperate basses	0.50	0.30	0.06	R06	143	0.00	3.59	0.00
Temperate basses	0.50	0.30	0.09	R08	151	0.00	3.53	0.00
Temperate basses	0.50	0.30	0.14	R09	156	128.40	0.00	0.83
Temperate basses	0.50	0.30	0.00	R10	159	19.64	0.00	1.61
Temperate basses	1.00	0.15	0.09	R03	133	2.68	0.00	0.00
Temperate basses	1.00	0.15	0.09	R06	146	225.59	3.15	0.00
Temperate basses	1.00	0.15	0.05	R07	149	22.64	2.11	4.76
Temperate basses	1.00	0.15	0.01	R08	154	11.41	0.00	3.59
Temperate basses	1.00	0.15	0.11	R09	157	39.34	0.00	0.00
Temperate basses	1.00	0.15	0.01	R10	162	6.91	0.00	0.00
Temperate basses	1.00	0.30	0.02	R02	129	3.27	0.00	0.00
Temperate basses	1.00	0.30	0.06	R04	137	1.57	0.00	0.00
Temperate basses	1.00	0.30	0.14	R06	145	85.42	0.00	0.00
Temperate basses	1.00	0.30	0.01	R07	150	12.68	0.00	0.00
Temperate basses	1.00	0.30	0.13	R09	158	83.56	1.82	0.00
Temperate basses	1.00	0.30	0.03	R10	161	8.30	1.74	0.00
Unknown	0.50	0.15	0.01	R01	123	0.00	0.00	0.36
Unknown	0.50	0.15	0.10	R02	128	0.00	0.00	0.41
Unknown	0.50	0.15	0.01	R03	131	5.73	3.41	1.56
Unknown	0.50	0.15	0.07	R04	136	2.82	0.00	0.00
Unknown	0.50	0.15	0.05	R05	139	0.00	1.59	0.00
Unknown	0.50	0.15	0.01	R06	144	5.14	179.59	0.00
Unknown	0.50	0.15	0.00	R07	147	0.00	0.44	0.00
Unknown	0.50	0.15	0.02	R08	152	0.00	2.18	0.00
Unknown	0.50	0.15	0.07	R09	155	0.00	2.58	1.56
Unknown	0.50	0.30	0.07	R01	124	0.00	0.58	0.00
Unknown	0.50	0.30	0.06	R02	127	0.00	3.53	0.54
Unknown	0.50	0.30	0.02	R03	132	0.00	2.67	0.00
Unknown	0.50	0.30	0.02	R04	135	1.75	0.43	2.01
Unknown	0.50	0.30	0.05	R05	140	5.02	0.00	1.59
Unknown	0.50	0.30	0.06	R06	143	0.00	0.00	1.66
Unknown	0.50	0.30	0.09	R08	151	6.30	3.53	0.82
Unknown	0.50	0.30	0.14	R09	156	0.00	23.26	3.34
Unknown	0.50	0.30	0.00	R10	159	6.55	10.32	0.00
Unknown	1.00	0.15	0.07	R01	125	2.35	0.43	0.00
Unknown	1.00	0.15	0.03	R02	130	0.00	0.00	0.89

Table C-1 (continued)
Entrainment data collected at the Portage River site

Species	Slot Width (mm)	Slot Velocity (m/s)	Mean Ambient Velocity (m/s)	Replicate	Trial #	Ambient Density (#/100m3)	Control Density (#/100m3)	Test Density (#/100m3)
Unknown	1.00	0.15	0.09	R03	133	0.00	0.00	0.41
Unknown	1.00	0.15	0.09	R06	146	0.00	4.95	0.00
Unknown	1.00	0.15	0.05	R07	149	0.00	0.00	4.76
Unknown	1.00	0.15	0.01	R08	154	0.00	64.97	0.00
Unknown	1.00	0.15	0.01	R10	162	0.00	0.00	369.01
Unknown	1.00	0.30	0.02	R01	126	4.93	0.00	0.46
Unknown	1.00	0.30	0.02	R02	129	0.00	0.00	0.23
Unknown	1.00	0.30	0.13	R03	134	3.02	0.00	0.66
Unknown	1.00	0.30	0.06	R04	137	1.57	0.00	1.13
Unknown	1.00	0.30	0.09	R05	142	0.00	13.89	3.68
Unknown	1.00	0.30	0.14	R06	145	0.00	0.00	0.90
Unknown	1.00	0.30	0.01	R08	153	0.00	0.43	120.48
Unknown	1.00	0.30	0.13	R09	158	0.00	0.00	18.35
Unknown	1.00	0.30	0.03	R10	161	954.59	5.22	1.76
Yellow Perch	0.50	0.30	0.06	R02	127	3.07	0.00	0.00
Yellow Perch	0.50	0.30	0.06	R06	143	13.58	0.00	0.00

D
WATER QUALITY DATA – ESTUARINE TESTING

Table D-1
Water Quality Data – Estuarine Testing

Trial #	Date	Time	DO (ppm)	Temp (°C)	Salinity (ppt)	Cond (µs/cm)	Turbidity (NTU)
1	4/7/2004	9:30	10.82	5.20	27.30	26.86	1.51
2	4/7/2004	11:50	11.10	5.20	26.70	25.97	1.81
3	4/7/2004	12:45	11.45	5.10	26.90	26.40	1.33
4	4/7/2004	14:15	26.85	5.30	27.00	26.67	1.00
6	4/8/2004	12:02	12.38	5.90	26.30	26.46	
7	4/8/2004	12:30	11.61	6.00	26.10	26.35	
9	4/8/2004	14:50	11.92	5.40	27.40	27.10	1.32
10	4/9/2004	10:59	11.19	6.00	27.00	27.17	1.45
11	4/9/2004	11:54	2.05	6.10	27.10	27.34	0.99
12	4/9/2004	12:31	12.04	6.10	27.00	27.25	1.06
13	4/9/2004	13:30	12.20	6.70	25.70	26.47	1.19
14	4/9/2004	14:33	12.34	6.80	26.20	27.01	1.83
15	4/9/2004	15:15	12.25	6.70	26.70	27.41	1.54
16	4/12/2004	13:39	11.99	7.00	27.60	28.47	1.03
17	4/12/2004	15:00	12.49	7.20	26.70	27.77	1.48
18	4/12/2004	16:16	12.39	7.10	27.10	28.07	1.87
19	4/12/2004	16:49	12.55	7.20	26.70	27.77	1.65
20	4/12/2004	17:46	12.60	7.20	16.80	27.87	1.45
21	4/12/2004	18:42	12.95	7.90	25.00	26.64	1.41
22	4/13/2004	2:36	11.44	6.80	27.00	27.17	1.63
23	4/13/2004	4:00	12.08	6.80	26.80	27.57	
24	4/13/2004	4:53	12.01	6.70	27.00	27.67	1.39
25	4/13/2004	6:00	11.76	6.60	27.60	28.17	2.30
26	4/13/2004	7:18	11.62	6.80	26.40	27.20	1.67
27	4/13/2004	8:20	11.50	6.60	26.60	27.24	1.16
28	4/16/2004	5:57	10.26	6.70	26.10	26.85	1.94
29	4/16/2004	7:11	10.37	6.70	26.20	26.94	1.95
30	4/16/2004	7:45	10.25	6.50	25.90	26.52	1.73
31	4/16/2004	8:37	10.13	6.80	25.80	26.64	1.63
32	4/16/2004	9:50	10.10	6.90	25.60	26.52	2.07
33	4/16/2004	10:33	10.02	7.00	25.20	26.21	1.75

Table D-1 (continued)
Water Quality Data – Estuarine Testing

Trial #	Date	Time	DO (ppm)	Temp (°C)	Salinity (ppt)	Cond (µs/cm)	Turbidity (NTU)
34	4/17/2004	6:40	10.05	6.80	26.10	26.92	1.95
35	4/17/2004	7:45	10.14	6.70	26.00	26.75	2.40
36	4/17/2004	8:20	10.04	6.90	26.80	27.65	1.49
37	4/17/2004	9:08	9.84	6.80	26.80	27.57	1.38
38	4/17/2004	10:22	9.91	7.00	26.80	27.72	1.37
39	4/17/2004	11:14	9.74	6.90	26.30	27.18	1.53
40	4/18/2004	7:24	9.71	7.50	26.10	27.42	1.12
41	4/18/2004	8:14	9.74	7.50	26.30	27.61	1.93
42	4/18/2004	9:18	9.91	7.60	25.80	27.20	1.67
43	4/18/2004	10:06	10.32	8.10	25.40	27.64	1.34
44	4/18/2004	11:15	10.30	8.50	25.20	27.54	1.67
45	4/18/2004	12:13	10.27	8.50	25.90	27.84	1.31
46	4/19/2004	7:51	9.45	8.20	27.30	29.17	1.47
47	4/19/2004	9:04	9.92	7.60	27.50	28.75	1.26
48	4/19/2004	9:58	9.84	7.60	27.10	28.71	1.17
49	4/19/2004	11:08	9.91	8.60	26.60	28.76	1.34
50	4/19/2004	12:13	9.84	8.00	27.40	29.00	2.05
51	4/19/2004	12:58	9.91	8.30	27.50	29.28	1.10
52	4/20/2004	8:45	10.12	9.50	24.50	27.25	1.88
53	4/20/2004	9:21	10.19	9.40	25.10	27.76	1.16
54	4/20/2004	10:12	10.38	9.60	25.00	27.64	1.70
55	4/20/2004	11:18	10.72	9.80	24.90	27.93	1.17
56	4/20/2004	12:26	10.85	10.50	24.30	27.42	1.22
57	4/20/2004	13:27	10.38	11.10	23.20	27.03	1.14
58	4/21/2004	9:09	10.54	9.50	26.10	28.26	1.38
59	4/21/2004	10:45	11.19	9.80	23.80	27.37	1.85
60	4/21/2004	11:01	10.97	9.80	25.70	28.21	1.80
61	4/21/2004	12:06	10.66	9.70	25.60	28.27	1.81
62	4/21/2004	13:15	10.90	9.90	24.40	27.44	1.21
63	4/21/2004	14:12	10.71	10.30	24.90	28.24	1.35
64	4/22/2004	9:38	9.19	9.60	27.60	30.46	1.77
65	4/22/2004	10:32	9.40	9.70	27.80	30.66	1.78
66	4/22/2004	11:41	9.59	8.70	27.50	29.80	2.59
67	4/22/2004	12:34	9.78	9.40	26.80	29.71	1.93
68	4/22/2004	13:56	10.03	9.20	26.70	29.69	2.11
69	4/22/2004	15:06	9.74	9.40	27.50	30.18	1.91
70	4/23/2004	10:02	9.68	9.90	27.30	30.34	1.05
71	4/23/2004	11:07	10.18	10.80	23.80	28.35	1.97

Table D-1 (continued)
Water Quality Data – Estuarine Testing

Trial #	Date	Time	DO (ppm)	Temp (°C)	Salinity (ppt)	Cond (µs/cm)	Turbidity (NTU)
72	4/23/2004	12:20	10.24	11.10	23.80	27.70	1.48
73	4/23/2004	13:37	10.22	11.00	24.10	28.01	1.50
74	4/23/2004	14:40	10.36	11.30	23.80	27.61	1.75
75	4/23/2004	15:40	10.33	10.70	24.20	28.10	1.77
76	4/24/2004	10:46	9.45	10.30	26.20	29.62	1.27
77	4/24/2004	12:00	9.52	9.90	25.50	28.30	1.01
78	4/24/2004	13:03	10.04	10.50	25.20	28.14	1.28
79	4/24/2004	14:24	10.31	11.10	23.70	27.53	1.65
80	4/24/2004	15:21	10.52	11.00	23.80	27.55	1.68
81	4/24/2004	16:30	10.36	11.80	22.50	26.71	1.51
82	4/25/2004	23:54	9.45	9.00	27.70	30.13	1.42
83	4/25/2004	0:53	9.37	8.80	27.40	29.74	1.52
84	4/25/2004	2:01	9.77	8.90	26.60	29.30	1.61
85	4/25/2004	3:11	9.78	9.30	26.30	28.58	1.44
86	4/25/2004	4:19	9.81	9.60	25.60	28.40	1.64
87	4/25/2004	5:20	9.81	9.80	24.50	27.80	1.60
88	4/27/2004	13:26	9.37	9.90	26.90	29.98	1.53
89	4/27/2004	15:01	10.43	10.10	26.00	29.28	1.74
90	4/27/2004	15:31	10.08	10.00	25.70	28.91	1.30
91	4/27/2004	16:33	10.26	10.10	26.30	29.22	1.88
92	4/27/2004	17:33	9.53	9.20	27.20	29.54	1.33
93	4/28/2004	14:08	9.89	11.70	22.10	26.35	1.72
94	4/28/2004	15:15	10.13	12.10	22.10	26.53	1.82
95	4/28/2004	16:18	9.64	11.20	23.80	26.47	1.39
96	4/28/2004	17:23	10.03	11.90	22.40	26.87	1.82
97	4/28/2004	18:30	9.93	12.00	22.00	26.93	1.87
98	4/28/2004	19:30	9.80	11.80	22.20	26.14	1.98
99	4/30/2004	16:20	8.34	11.00	27.40	31.30	0.93
100	4/30/2004	17:20	8.22	10.40	27.30	30.77	1.06
101	4/30/2004	18:23	8.17	10.30	27.20	30.55	1.41
102	4/30/2004	19:27	8.44	10.40	26.70	30.16	1.24
103	4/30/2004	20:37	8.15	10.20	27.20	30.43	1.30
104	4/30/2004	21:50	8.19	10.30	27.00	30.28	1.43
105	5/1/2004	17:00	7.23	11.50	27.20	31.45	1.71
106	5/1/2004	18:07	7.78	10.80	27.30	31.16	1.41
107	5/1/2004	19:13	7.72	10.70	27.30	31.00	1.57
108	5/1/2004	20:16	7.76	10.80	27.10	30.85	1.41
109	5/1/2004	21:23	7.72	10.90	26.90	30.75	1.75
110	5/1/2004	22:28	7.74	11.20	26.60	30.65	1.61

Table D-1 (continued)
Water Quality Data – Estuarine Testing

Trial #	Date	Time	DO (ppm)	Temp (°C)	Salinity (ppt)	Cond (µs/cm)	Turbidity (NTU)
111	5/2/2004	18:09	7.34	12.20	27.50	32.30	2.32
112	5/2/2004	19:08	7.43	11.30	27.60	31.76	1.97
113	5/2/2004	20:13	7.35	10.80	27.60	31.74	1.78
114	5/2/2004	21:41	7.05	10.70	27.60	31.43	1.29
115	5/2/2004	22:26	7.32	10.80	27.40	31.26	1.30
116	5/2/2004	23:35	6.62	11.30	27.50	31.61	1.16
117	5/3/2004	18:44	6.48	12.20	27.50	32.31	1.17
118	5/3/2004	19:50	7.11	12.10	26.20	30.85	2.19
119	5/3/2004	21:40	7.94	11.60	26.60	31.06	2.20
120	5/3/2004	22:48	8.17	11.50	26.80	31.03	1.79
121	5/3/2004	12:10	8.12	11.90	26.40	30.93	1.45
122	5/5/2004	13:05	8.76	11.80	26.40	30.87	1.33

E
WATER QUALITY DATA – FRESHWATER TESTING

Table E-1
Water Quality Data – Freshwater Testing

Trial #	Date	Time	DO (ppm)	Temp (°C)	Salinity (ppt)	Cond (µs/cm)	Turbidity (NTU)
123	5/15/2004	9:02	10.3	16.1	0.1	0.2	12.1
123	5/15/2004	12:48	10.2	15.9	0.1	0.2	11.2
124	5/15/2004	13:19	10.1	15.9	0.1	0.2	12.5
124	5/15/2004	16:50	10.1	17.2	0.2	0.3	17.4
125	5/16/2004	7:22	9.4	16.6	0.2	0.3	22.5
125	5/16/2004	10:45	9.5	17	0.2	0.3	26.7
126	5/16/2004	11:17	9.7	17	0.2	0.3	25
126	5/16/2004	14:47	10.9	17.6	0.2	0.3	21.6
127	5/17/2004	8:06	10.2	17.2	0.2	0.3	18
127	5/17/2004	12:18	12.2	19	0.2	0.4	18.4
128	5/17/2004	15:10	13.3	20.5	0.3	0.4	18.8
128	5/17/2004	13:18	12	19	0.2	0.4	18.1
129	5/18/2004	10:06	10	18.5	0.2	0.3	12.9
129	5/18/2004	12:09	10.4	18.9	0.2	0.3	11.7
130	5/18/2004	14:00	10.3	18.7	0.2	0.3	11.6
130	5/18/2004	15:58	10.5	18.5	0.2	0.2	10.4
131	5/19/2004	7:31	9.5	17.9	0.2	0.3	24.1
131	5/19/2004	9:34	9.5	17.8	0.2	0.3	21.5
132	5/19/2004	11:45	9.6	17.5	0.2	0.3	14.9
132	5/19/2004	13:43	10.6	17.9	0.2	0.2	12.3
133	5/20/2004	9:10	11.1	19.6	0.3	0.5	22.4
133	5/20/2004	11:23	11.7	20.4	0.3	0.5	18.5
134	5/20/2004	15:08	12.9	21.9	0.3	0.5	21.1
134	5/20/2004	13:37	12.8	21.2	0.3	0.5	18.4
135	5/21/2004	9:16	9.6	19.4	0.2	0.3	10.2
135	5/21/2004	11:16	9.7	19.9	0.2	0.3	10.6
136	5/21/2004	13:38	10.3	20.7	0.2	0.3	12.3
137	5/22/2004	9:12	9	20.5	0.2	0.4	39.5
137	5/22/2004	11:14	8.9	20.9	0.2	0.4	39.2
138	5/22/2004	15:23	10.8	22.4	0.2	0.4	27.2
138	5/22/2004	13:26	9.8	21.6	0.2	0.4	22.6

Table E-1 (continued)
Water Quality Data – Freshwater Testing

Trial #	Date	Time	DO (ppm)	Temp (°C)	Salinity (ppt)	Cond (µs/cm)	Turbidity (NTU)
139	5/23/2004	11:00	8.2	23	0.3	0.6	28.6
139	5/23/2004	12:58	8.5	23.5	0.3	0.5	26.6
140	5/23/2004	15:07	8.4	23.6	0.3	0.6	25.5
140	5/23/2004	17:07	9.9	24.3	0.3	0.6	28.5
141	5/24/2004	9:01	7	22	0.3	0.6	47.2
141	5/24/2004	7:11	6.5	22.5	0.3	0.6	40.7
142	5/24/2004	10:57	7.4	22.1	0.3	0.6	52.9
142	5/24/2004	12:55	7.6	22	0.3	0.6	61.1
143	5/25/2004	10:13	7.6	19.5	0.2	0.3	39.2
143	5/25/2004	12:13	7.6	19.6	0.2	0.3	33.6
144	5/25/2004	16:23	8.8	20.1	0.1	0.2	10.7
144	5/25/2004	14:28	8.7	20.1	0.2	0.3	22.6
145	5/26/2004	9:33	8.1	20	0.2	0.2	17.9
145	5/26/2004	11:37	8.3	20.8	0.2	0.3	28
146	5/26/2004	13:39	8.8	21.7	0.2	0.3	29.8
146	5/26/2004	15:38	9.3	22.3	0.2	0.4	28.7
147	5/27/2004	9:39	8.8	20.7	0.2	0.3	28.5
147	5/27/2004	11:39	9.1	20.3	0.2	0.2	11.8
148	5/27/2004	13:45	9.1	20.3	0.2	0.2	10.7
148	5/27/2004	15:45	9.7	21.1	0.2	0.3	20.3
149	5/28/2004	9:40	8.9	20.4	0.2	0.3	22.6
149	5/28/2004	11:40	8.9	20.3	0.2	0.3	24.7
150	5/28/2004	13:50	8.7	20.3	0.2	0.3	28.9
150	5/28/2004	15:52	8.6	19.7	0.2	0.2	15.8
151	5/29/2004	9:35	8.6	18.7	0.2	0.4	25.2
151	5/29/2004	11:39	9.4	19.1	0.3	0.5	42.8
152	5/29/2004	13:40	10.4	19.6	0.3	0.5	32.6
152	5/29/2004	15:40	10.5	19.7	0.3	0.5	41.1
153	5/30/2004	12:58	9.9	19.1	0.2	0.3	13.5
153	5/30/2004	14:58	9.8	19.6	0.2	0.3	14.1
154	5/30/2004	17:03	11.1	20.2	0.2	0.3	12.5
155	5/31/2004	9:44	9.7	19.7	0.2	0.4	38.5
155	5/31/2004	11:43	9.2	19.9	0.3	0.4	45.4
156	5/31/2004	13:50	9.8	20.4	0.2	0.4	44.5
156	5/31/2004	15:50	10.3	21	0.3	0.5	58.8
157	6/1/2004	9:35	10.6	19.1	0.3	0.5	54.6
157	6/1/2004	11:35	10.6	19.6	0.3	0.5	57.6
158	6/1/2004	13:40	11.6	20.2	0.3	0.6	57.4
158	6/1/2004	15:47	11.5	20.6	0.3	0.6	60.6

Table E-1 (continued)
Water Quality Data – Freshwater Testing

Trial #	Date	Time	DO (ppm)	Temp (°C)	Salinity (ppt)	Cond (µs/cm)	Turbidity (NTU)
159	6/3/2004	9:40	7	19	0.3	0.4	94.7
159	6/3/2004	11:40	7.8	19.4	0.2	0.4	49.9
160	6/3/2004	13:50	7.8	20	0.3	0.4	61.6
160	6/3/2004	15:50	8.9	21.7	0.3	0.4	69.4
161	6/4/2004	11:35	7.9	19.7	0.2	0.4	61.9
161	6/4/2004	9:45	8.4	19.5	0.2	0.4	66
162	6/4/2004	13:45	8.3	19.9	0.2	0.4	58.5
162	6/4/2004	15:45	8.6	20.2	0.2	0.4	56

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